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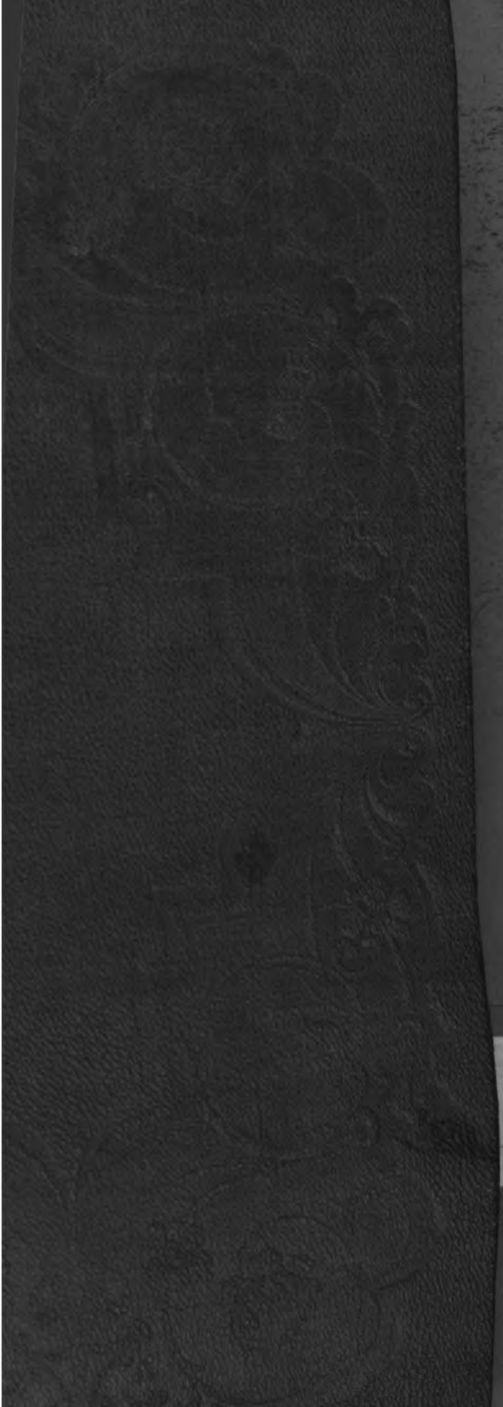

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PREFACE.

The following Lectures were addressed to a Society[*] of practical agriculturists, many of whom possessed no knowledge whatever of scientific Chemistry or Geology. They commence, therefore, with the discussion of those elementary principles which are necessary to a proper understanding of each branch of the subject. Every thing in such Lectures, which is not—or may not be—easily understood by those to whom they are addressed, is worse than useless. It is my intention, therefore, to employ no scientific terms, and to refer to no philosophical principles, which I have not previously explained. Having been requested to publish these Lectures for the benefit of practical agriculturists in general, I have endeavoured to adapt them to the average knowledge of that class. To many who may take up the later Lectures, some points may appear obscure or difficult to be fully understood; such persons will, I hope, do me the justice to begin at the beginning, and to blame the author only when that which is necessary to the understanding of the later, is not to be found in the earlier Lectures. Those who possess a certain amount of chemical knowledge will derive much benefit from a perusal of Liebig's "Organic Chemistry, in its applications to Agriculture and Physiology;" and from "Three Lectures on Agriculture," by Professor Daubeny, of Oxford.

---

[*] The Durham County Agricultural Society, and the Members of the Durham Farmers' Club.

For the sake of clearness, I have, in the following pages, divided the subject into *four* parts, the study of each preceding part preparing the way for a complete understanding of those which follow. Thus the first part is devoted to the *organic elements* and parts of plants, the nature and sources of these elements, and an explanation of the mode in which they become converted into the substance of plants—the second to the *inorganic elements* of plants, comprehending the study of the soils from which these elements are derived—with the general relations of geology to agriculture—the third to the *nature of manures*, by which soils are made more productive, and the amount of vegetable produce increased—and the fourth, to the *results of vegetation*—to the kind and value of the food produced under different circumstances—and its relation to the growth of cattle, and to the amount and quality of dairy produce.

By this method I have endeavoured to ascend from the easy to the apparently difficult; and I trust that the willing and attentive reader will find no difficulty in keeping by my side during the entire ascent.

Durham, 1841.

CONTENTS.

LECTURE I.

IMPORTANCE OF AGRICULTURE.—RELATION OF THE GROWTH OF FOOD TO THE POPULATION OF GREAT BRITAIN.—RECENT PROGRESS AND PROSPECTS OF ENGLISH AGRICULTURE.—APPLICATION OF CHEMICAL AND GEOLOGICAL SCIENCE TO THE ART OF CULTURE, TO THE IMPROVEMENT OF SOILS, THE ROTATION OF CROPS, THE APPLICATION OF MANURES, &C.—OUTLINE OF THE COURSE OF LECTURES.—NUMBER AND NATURE OF THE ELEMENTARY BODIES.—THE ORGANIC ELEMENTS CARBON, HYDROGEN, OXYGEN, AND NITROGEN, THEIR PROPERTIES AND THEIR RELATIONS TO VEGETABLE LIFE.

Introduction . . . . p. 3
§ 1. Different kinds and states of matter 19
§ 2. Carbon, its properties and relations to vegetable life . . 22
§ 3. Oxygen, its properties and relations to vegetable life . . 24
§ 4. Hydrogen, its properties and relations to vegetable life . 26
§ 5. Nitrogen, its properties and relations to vegetable life . 27
Rewards of study 28

LECTURE II.

CHARACTERISTIC PROPERTIES OF ORGANIC SUBSTANCES.—RELATIVE PROPORTIONS OF ORGANIC ELEMENTS.—VARIABLE PROPORTIONS OF INORGANIC ELEMENTS IN PLANTS.—FORM IN WHICH THE ORGANIC ELEMENTS ARE TAKEN UP BY PLANTS.—THE ATMOSPHERE, ITS CONSTITUTION AND RELATIONS TO VEGETABLE LIFE.—NATURE AND LAWS OF CHEMICAL COMBINATION.—WATER AND ITS RELATIONS TO VEGETABLE LIFE.

§ 1. Characteristic properties of organic substances 30
§ 2. Relative proportions of organic elements 33

§ 3. Of the form or state of combination in which the organic elements enter into and minister to the growth of plants . p. 34
§ 4. On the constitution of the atmosphere 35
§ 5. The nature and laws of chemical combination . . . 37
§ 6. Of water, and its relations to vegetable life . . . 42
§ 7. Of the cold produced by the evaporation of water, and its influence on vegetation 53

LECTURE III.

CARBONIC AND OXALIC ACIDS, THEIR PROPERTIES AND RELATIONS TO VEGETABLE LIFE—CARBONIC OXIDE AND LIGHT CARBURETTED HYDROGEN, THEIR PROPERTIES AND PRODUCTION IN NATURE—AMMONIA, ITS PROPERTIES AND RELATIONS TO VEGETABLE LIFE.

§ 1. Carbonic acid, its properties and relations to vegetable life . 57
§ 2. Oxalic acid, its properties and relations to vegetable life . 61
§ 3. Carbonic oxide, its constitution and properties . . . 63
§ 4. Light carburetted hydrogen, the gas of marshes and of coal mines 64
§ 5. Ammonia, its properties and relations to vegetable life . 65

LECTURE IV.

SOURCE OF THE ORGANIC ELEMENTS OF PLANTS—SOURCE OF THE CARBON—FORM IN WHICH IT ENTERS INTO THE CIRCULATION OF PLANTS—SOURCE OF THE HYDROGEN—SOURCE OF THE OXYGEN—SOURCE OF THE NITROGEN—FORM IN WHICH NITROGEN ENTERS INTO THE CIRCULATION OF PLANTS—ABSORPTION OF AMMONIA AND NITRIC ACID BY PLANTS.

§ 1. Source of the carbon of plants 78
§ 2. Form in which carbon enters into the circulation of plants 85
§ 3. Source of the hydrogen of plants 88
§ 4. Source of the oxygen of plants 90
§ 5. Source of the nitrogen of plants 91
§ 6. Form in which the nitrogen enters into the circulation of plants 94
§ 7. Absorption of ammonia by plants 97
§ 8. Absorption of nitric acid by plants 101
Conclusions 103

LECTURE V.

HOW DOES THE FOOD ENTER INTO THE CIRCULATION OF PLANTS—STRUCTURE OF THE SEVERAL PARTS OF PLANTS—FUNCTIONS OF THE ROOT—COURSE OF THE SAP—CAUSE OF ITS ASCENT—FUNCTIONS OF THE STEM—OF THE LEAVES—AND OF THE BARK—CIRCUMSTANCES BY WHICH THE EXERCISE OF THESE FUNCTIONS IS MODIFIED.

§ 1. General structure of plants, and of their several parts . p. 105
§ 2. The functions of the root 108
§ 3. The course of the sap 121
§ 4. Functions of the stem 126
§ 5. Functions of the leaves 128
§ 6. Functions of the bark 138
§ 7. Circumstances by which the functions of the various parts of plants are modified 140

LECTURE VI.

SUBSTANCES OF WHICH PLANTS CHIEFLY CONSIST—WOODY FIBRE, STARCH, GUM, SUGARS—THEIR MUTUAL RELATIONS AND TRANSFORMATIONS—GLUTEN, VEGETABLE ALBUMEN, DIASTASE—ACETIC, TARTARIC, MALIC, CITRIC, AND OXALIC ACIDS—GENERAL OBSERVATIONS.

Substances of which plants chiefly consist 148
§ 1. Woody fibre or lignin—its constitution and properties . 150
§ 2. Starch—its constitution and properties 155
§ 3. Gum—its constitution and properties 157
§ 4. Of Sugar—its varieties and chemical constitution . . 159
§ 5. Mutual relations of woody fibre, starch, gum, and sugar . 161
§ 6. Mutual transformations of woody fibre, starch, gum, and sugar 163
I. Woody fibre . . . . ib.
II. Starch 165
III. Gum 166
IV. Cane Sugar . . . . ib.
Of the fermentation of starch and sugar, and of the relative circumstances under which cane and grape sugars generally occur in nature 168

§ 8. Of substances which contain nitrogen, gluten, vegetable albumen, and diastase . . . . p. 170
§ 9. Vegetable Acids.—Acetic acid, oxalic acid, tartaric acid, citric acid, malic acid 178
I. Acetic acid . . . . ib.
1°. By the distillation of wood 179
2°. Manufacture of vinegar from cane sugar . . 180
3°. Manufacture of vinegar from alcohol . . . 182
4°. Production of vinegar by fermentation . . 133
II. Tartaric acid 184
III. Citric acid or acid of lemons 184
IV. Malic acid 185
V. Oxalic acid 186
§ 10. General observations on the substances of which plants chiefly consist 187

LECTURE VII.

CHEMICAL CHANGES BY WHICH THE SUBSTANCES OF WHICH PLANTS CHIEFLY CONSIST ARE FORMED FROM THOSE ON WHICH THEY LIVE—CHANGES DURING GERMINATION—DURING THE GROWTH OF THE PLANT—DURING THE RIPENING OF FRUIT—AUTUMNAL CHANGES.

§ 1. Chemical changes which take place during germination, and during the developement of the first leaves and roots . 195
§ 2. Of the chemical changes which take place from the formation of the true leaf to the expansion of the flower . 201
§ 3. On the production of oxalic acid in the leaves and stems of plants 206
§ 4. Of the chemical changes which take place between the opening of the flower and the ripening of the fruit or seed 208
1. Formation of the seed 209
2. Ripening of the fruit 210
§ 5. Of the chemical changes which take place after the ripening of the fruit and seed 214
§ 6. Of the rapidity with which these changes take place, and the circumstances by which they are promoted . . 215

LECTURE VIII.

HOW THE SUPPLY OF FOOD IS KEPT UP IN THE GENERAL VEGETATION OF THE GLOBE—PROPORTION OF THEIR FOOD DRAWN BY PLANTS FROM THE AIR—SUPPLY OF CARBONIC ACID—SUPPLY OF AMMONIA AND NITRIC ACID—PRODUCTION OF BOTH IN NATURE—THEORY OF THEIR ACTION ON LIVING VEGETABLES—CONCLUDING OBSERVATIONS.

§ 1. Of the proportion of their carbon which is derived from the atmosphere . . . . p. 218
§ 2. Of the relation which the quantity of carbon extracted by plants from the air, bears to the whole quantity contained in the atmosphere 221
§ 3. How the supply of carbonic acid in the atmosphere is renewed and regulated 223
  I. On the production of carbonic acid by respiration . 22
  II. On the production of carbonic acid by combustion . 225
  III. Production of carbonic acid by the natural decay of vegetable matter. Law of this decay 227
  IV. Natural evolution of carbonic acid in volcanic countries 230
  Conclusions 234
§ 4. Of the supply of ammonia to plants 233
§ 5. Of the supply of nitric acid to plants 237
§ 6. Theory of the action of nitric acid and ammonia . . 245
  I. Theory of the action of nitric acid . . . . . ib.
  II. Theory of the action of ammonia 247
§ 7. Comparative influence of nitric acid and of ammonia in different climates 249
§ 8. Stimulating inflence of these compounds 250
Concluding observations regarding the organic constituents of plants 253

APPENDIX.

No. I.

Suggestions for Experiments in Practical Agriculture . p. 1
I. Of Grass and Clover 2
II. Of Wheat, Barley, and Oats 7
A. Of Wheat . . . . ib.
B. Of Barley and Oats 9
III. Of Turnips 10
IV. Of Potatoes 15

No. II.

Of the Effect of Sudden Alternations of Temperature on Vegetable Substances 18

No. III.

Results of Experiments on Practical Agriculture during the Spring and Summer of 1841 21

No. IV.

Suggestions for Comparative Experiments with Guano and other Manures 38

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PART II.

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Lecture IX.

Inorganic elements of vegetable substances.—Relative proportions of organic and inorganic matter in plants.—Unlike proportions in unlike species.—Kind of organic matter which exists in different species.—Nature and properties of the several inorganic elementary bodies found in plants.

Lecture X.

Inorganic constituents of plants, continued.—Magnesia, alumina, silica, and the oxides of iron and manganese.—Tabular view of the constitution of the inorganic substances described.—Proportions in which these several substances are found in the plants cultivated for food.—Extent to which these plants exhaust the soil of inorganic vegetable food.—State in which the inorganic elements exist in plants.

PART III.

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WERE I about to address you in a single or detached Lecture only, I should think it my duty to select some one branch of the art of culture for special illustration, and without much introductory matter to proceed at once to the exposition of the principle or principles on which it depended. As the present, however, is only the first of a Series of Lectures I hope to have the honor of delivering to you, I may be permitted to introduce my subject with a few prefatory remarks, which will here find their appropriate place.

In regard to the importance of Agriculture it may appear superfluous in me to address you. That art on which a thousand millions of men are dependent for their very sustenance—in the prosecution of which nine-tenths of the fixed capital of all civilized nations is embarked—and probably two hundred millions of men expend their daily toil—that art must confessedly be the most important of all; the parent and precursor of all other arts. In every country then, and at every period, the investigation of the principles on which the rational practice of this art is founded, ought to have commanded the principal attention of the greatest minds. To what other object could they have been more beneficially directed?

But there are periods in the history of every country when the study of Agriculture becomes more urgent, and in that country acquires a vastly superior importance. When a tract of land is thinly peopled, like the newly settled districts of North America, New Holland, or New Zealand, a very defective system of culture will produce food enough not only for the wants of the inhabitants, but for the partial supply of other countries also. But when the population becomes more dense, the same imperfect or sluggish system will no longer suffice. The land must be better tilled, its special qualities and defects must be studied, and means must gradually be adopted for extracting the maximum produce from every portion susceptible of cultivation.

The British islands are in this latter condition. Agriculture now is of vastly more importance to us as a nation, than it was towards the close even of the last century. In 1780, the island of Great Britain contained about 9 millions of inhabitants; it now contains nearly 20. The land has not increased in quantity, but the consumption of food has probably more than doubled. The importation from abroad has not increased to any important extent; by improved management, therefore, the same area of land has been caused to yield a double produce.

But the population will continue to increase; can we expect that the food raised from the land will continue to increase in the same ratio? This is an important question, to which we can give only an imperfect and somewhat unsatisfactory answer.

The superficial area of Great Britain comprises about 57 millions of acres, of which 34 millions are in cultivation, about 13 millions are incapable of culture, and the remaining 10 millions are waste lands susceptible of improvement. The present population, therefore, is supported by the produce of 34 millions of acres, or every 34 acres raises food for about 20 people. Suppose the 10 millions of acres which are susceptible of improvement to be brought into such a state of culture as to maintain an equal proportion—the most favourable supposition—they would raise food for an additional population of about 6 millions, or would keep Great Britain independent of any large and constant foreign supply till the number of its inhabitants amounted to 26 millions. But at the present rate of increase this will take place in about 20 years,* so that by 1860, unless some general improvement take place in the agriculture of the country, the demands of the population will have completely overtaken the productive powers of the land.

But though we cannot say how far the fertility of the soil may be increased, or how long it may be able to keep a-head of the growing numbers of the people, we have our own past experience, the example of other countries, and the indications of theory, all concurring to persuade us that the limit of its productive powers can neither be predicted nor foreseen.

If we glance at the history of British agriculture during the last half century—from the introduction of the green-crop system or the alternate husbandry from Flanders into Norfolk, up to the present time—we find the results of each successive improvement more remarkable than the former. The use of lime, a more general drainage of the soil, the invention of improved ploughs and other agricultural implements, as well as the introduction of better and more economical modes of using them, the application of bone manure, and more recently of thorough draining and subsoil ploughing, have all tended not only to the raising of crops at a less cost, but in far greater abundance, and on spots which our forefathers considered wholly unfit for the growth of corn.

The result of each new improvement, I have said, has seemed more astonishing than the former. For after a waste piece of land has been brought into an average state of productiveness, we are not prepared for any great improvement upon it by new labours; nor could we readily believe that, half a century after such land had been in culture, its produce or its value should at once be doubled, by a better draining, a deeper ploughing, or by sprinkling on its surface a small quantity of a saline substance imported from a foreign country.

Yet the example of the Chinese shows us that the productive powers of the soil are not to be easily estimated. Nothing repays the labors of the husbandman more fully than the willing soil—nothing is more grateful for his attention, or offers surer rewards to patient industry, or to renewed attempts at improvement.

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* For more precise data and calculations see *Porter's Progress of the Nation.*

In China we see a people whom we call semi-barbarians, multiplying within their own limits till their numbers are almost incredible; practising from the most remote ages, and in the most skilful manner, various arts which the progress of modern science has but recently introduced into civilized Europe; cultivating their soil with the most assiduous labor, and stimulating its fertility by means which we have hitherto neglected, despised, or been wholly ignorant of—but which the discoveries of the present time are pointing out as best fitted to secure the amplest harvests—and have thus been enabled to compel their limited soil to yield a sufficient sustenance to its almost unlimited population.*

Experience and example, therefore, encourage us to look forward to still further improvements in the art of culture, and, independent of such as may be derived from purely mechanical principles, theoretical chemistry seems to point out the direction in which important advances of another kind may reasonably be anticipated. The Chinese are said to be not only familiar with the relative value and efficiency of the various manures, but also to understand how to prepare and apply without loss that which is best fitted to stimulate and support each kind of plant. How far this statement is exaggerated we are unable at present to determine, but it is in this direction that chemistry appears likely to promote the advance of European agriculture. The practical farmer already rejoices in having in one ton of bone dust the equivalent of 14 tons of farm-yard manure; some of the most skilful living chemists predict that methods will hereafter be discovered for compressing into a still less bulky form the substances required by plants, and that we shall live to see extensive manufactories established for the preparation of these condensed manures.*

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* An intelligent correspondent reminds me that the agricultural skill of the Chinese is questioned by recent writers on the customs of that country. This doubt is founded chiefly on the rudeness of their agricultural implements and the scarcity of cattle, whether horses or cows, among them. But in this densely peopled country the hoe they employ serves the purpose of every other implement (*Davis's China*, ii. 282), and, where the place of cattle is supplied by an equivalent number of men, there can be no comparative want of valuable manure. The population of China, however, is probably not so dense in all the provinces as it has hitherto been supposed. Many writers have estimated the entire population at 300 millions, while recent statists reduce it to 175 millions. Taking even the higher estimate, the population is not more dense than in England and Holland—the area of China proper being 1,200,000 square miles, or eight times that of France. It is considerably less dense, indeed, if we take into account the number of horses and cattle which in Europe are reared and fed on the produce of the land. We may hereafter expect more accurate information, however, especially regarding the interior of this interesting country.—*See Appendix A.*

Thus much may be said in regard to the future hopes and prospects of scientific agriculture.† But how few practical men are acquainted with what is already known of the principles of the important art by which they live! Trained up in ancient methods—attached generally to conservative principles in every shape—the practical agriculturists, as a body, have always been more opposed to change than any other large class of the community. They have been slow to believe in the superiority of any methods of culture which differed from their own, from those of their fathers, or of the district in which they live—and, even when the superiority could no longer be denied, they have been almost as slow to adopt them.

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* Should the opinions above expressed appear too sanguine to some, or be treated by any of my readers as *merely theoretical*, I would refer them to the words of Mr. Smith, of Deanston, the inventor of the subsoil plough, and the introducer of the greatest practical improvement in modern agriculture. After stating that *at least three-fourths of the whole arable land in the country is under very indifferent culture*, chiefly from the want of complete draining and deep working, and, adverting to the increased produce it may be made to yield, he says, "it is not at all improbable that Britain may become an exporting country in grain in the course of the next twenty years."—*Remarks on thorough draining and deep ploughing, by James Smith, Esq., of Deanston Works, p.* 22. Were the population to remain stationary, Mr. Smith may be right; at all events, this opinion shows that even practical men do not despair of attaining to a pitch of improvement in agriculture which theoretical writers dare not venture to predict.

But among all persons of enlarged information a similar opinion prevails. Thus the eloquent author of a recent work on the principles of population says, "the single alteration of substituting the kitchen-garden husbandry of Flanders in our plains, and the terraced culture of Tuscany in our hills, for the present system of agricultural management, would at once double the produce of the British islands, and procure ample subsistence for twice the number of its present inhabitants." —*Alison's Principles of Population; I. p.* 216. These hopes are not to be rejected or suppressed; for, though they may never be fully realized, yet they are, as it were, the seeds of exertion, from which ample harvests of good may hereafter be reaped.

† Those who have access to the Journal of the Royal English Agricultural Society will find in the first number a paper by Mr. Pusey,

But the awakening spirit of the time is making itself felt in the remotest agricultural districts; old prejudices are dying out, and the cultivators of this most ancient, most important, and noblest of all the arts, are becoming generally anxious for information, and eager for improvement.*

Two circumstances have contributed to retard the approach of this better state of things.

In the first place, the agricultural interest in England has hitherto expended its main strength in attempting to secure or maintain important political advantages in the state. The encouragement of experimental agriculture has been in gene-

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"On the present state of the science of Agriculture in England," in which much valuable information is contained, and of a more practical kind than I have been able to introduce. This paper ought to be printed in a separate form, and circulated widely among those who are not members of the Royal English Agricultural Society.

* This opinion has been confirmed by the numerous communications I have received from all parts of the country since the publication of these Lectures was announced, and in which I am assured that the want of knowledge is generally felt, and a supply in a sufficiently elementary form desired, by all classes of agriculturists. I conclude, therefore, that Liebig means the following sentence to apply to his German countrymen: "What can be expected from the present (generation of) farmers, which recoils with seeming distrust and aversion from all the means of assistance offered it by chemistry, and which does not understand the art of making a rational application of chemical discoveries." I do not think chemists ought in fairness to blame the practical agriculturists for not understanding the art of applying chemical discoveries to the improvement of the culture of the land. They must first know what the discoveries are; and the error has hitherto been, that no steps have been taken to diffuse this preliminary knowledge.

ral neglected, while the diffusion of practical knowledge has been either wholly overlooked or considered subordinate to other objects. No national efforts have been made for the general improvement of the methods of culture. While for the other important classes of the community special schools have been established, in which the elements of all the branches of knowledge most necessary for each class have been more or less completely taught, and a more enlightened, because better instructed, race of men gradually trained up, no such schools have been instituted for the benefit of the agriculturist. In our Universities, in which the holders of land, those most interested in its improvement, are nearly all educated, a lesson upon agriculture, the right arm of the State, has hitherto scarcely ever been given.* With the practice of the art, the theory has also been neglected. Scientific men have had no

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* However satisfied young men may be to avoid the labor of additional study while at College, how many in after-life regret that their early attention had not been directed to some of those branches of knowledge which are applicable to common life. Thus the late Lord Dudley, in his letters to the Bishop of Llandaff, invariably laments, "as mistakes in his early life, his unacquaintance with the rudiments of agriculture—his ignorance of botany and geology."—(See also a note to the Review of these Letters in the Quarterly Review for December, 1840.)

For this state of things we shall soon have at least a partial remedy. It is a remarkable fact that nearly all the new educational institutions of the higher class, on the Continent of Europe, of which so many have been founded within the present century, and all those which have been established in America, I believe, without exception, have incorporated into their course of general study one or more of the newer sciences. Can we have a more consentaneous and universal testimony to their value and importance than this? The University of London has been induced, by the same public demand for this species of instruction, to include Chemistry and Botany in its course of arts; and circumstances only have caused Geology to be omitted for a time. Its numerous affiliated institutions have followed its steps; and hence the Catholic College of St. Cuthbert, at Ushaw, has in this respect anticipated its Protestant neighbor at Durham.

But should the agricultural interest rest satisfied with this introduction of one or two branches, suppose it generally done, into the University course of study? Many are of opinion that it ought not, and that the general interests of practical agriculture would be manifestly promoted, among other means, by the establishment of agricultural colleges, in which all the branches necessary to be known by enlightened agriculturists of every class should be specially and distinctly inducement to devote their time and talents to a subject which held out no promise of reward, either in the shape of actual emolument or of honorary distinction. And thus has arisen the second of those circumstances, by which I consider the approach of a better state of things to have been retarded—namely, the want of an *Agricultural Literature.*

With the exception of a small number of periodical publications, none of these even too well supported, by which attempts have been zealously made to diffuse important information among the practical farmers—it cannot be denied that the press has not been encouraged to do its utmost on behalf of agricultural knowledge in general—while the single work of Sir Humphry Davy is nearly all that chemical science has, in this country, been induced to contribute to the advancement of agricultural theory during the last forty years.*

Many of you have probably read this work of Sir H. Davy, and are prepared to acknowledge its value. Yet how many things does he pass over entirely, how many things leave unexplained. Since his time, not only have numerous practical observations and discoveries been made, but the entire science of animal and vegetable chemistry has been regenerated. We are not, therefore, to expect in his work a view of the present state, either of our theoretical knowledge, or of our practical agriculture. It belongs rather to the history of the progress of knowledge, than to the condition of existing information. Hence the merits of the agricultural chemistry of Davy are not to be tried by its ac-

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taught. Whether such Colleges might be beneficially annexed to the existing Universities, is a question deserving of serious consideration.

* The latest edition of Lord Dundonald's "Treatise on the intimate connection between Chemistry and Agriculture," which I have seen, is dated London, 1803.

I should be doing injustice to a good chemist and a zealous agriculturist, were I not to direct the attention of my readers to a series of excellent articles on chemical agriculture by Dr. Madden, inserted in the numbers of the Quarterly Journal of Agriculture for the last two years.

Since the above went to press, Three Lectures on Agriculture have appeared from the pen of Dr. Daubeny, of Oxford, whose name will secure them an extended circulation.

cordance with actual knowledge, but with what was known in 1812, when its distinguished author read his course of lectures for the last time before the Board of Agriculture.

We may with certainty predict, however, that neither the practice nor the theory of agriculture will be permitted to experience in future that want of general encouragement under which during the last half century they have in England been permitted to languish. The public mind has been awakened, and the establishment of Agricultural Associations, provincial and local, are manifestations of the interest now felt upon the subject in all parts of the country. It requires only the general exhibition of such an interest, and the adoption of some general means of encouragement, to stimulate both practical ingenuity and scientific zeal to expend themselves on this most valuable branch of national industry.

Science is never unwilling to lend her hand to the practical arts; on the contrary, she is ever forward to proffer her assistance, and it is not till her advances have been rejected or frequently repulsed, that she refrains from aiding in their advancement.

Need I advert, in proof of this, to the unwearied labours of the vegetable physiologists—or to the many valuable observations and experiments recorded in the memoirs of scientific chemists. In these memoirs, or in professedly scientific works, such observations have not unfrequently been permitted to rest;—the public mind being unprepared either to appreciate their value or to encourage the exertions of those who were willing to give them a practical and popular form.

And how numerous are the branches of science connected with this art? Need I speak of botany, which is, as it were, the foundation on which the first elements of agriculture rest; or of vegetable physiology, to the indications of which it has hitherto almost exclusively looked for improvement and increased success; or of zoology, which alone can throw light on the nature of the numerous insects that prey upon your crops, and so often ruin your hopes,—and which can alone be reasonably expected to arm you against their ravages, and instruct you to extirpate them? Meteorology among her other labours tabulates the highest, the mean, and the lowest, temperatures, as well as the quantity of rain which falls during each day and each month of the year. Do you doubt the importance of such knowledge to the proper cultivation of the land? Consider the destructive effects of a late frost in spring, or of a continued heat in summer, and your doubts will be shaken. A wet season in our own climate brings with it many evils to the practical agriculturist; but what effect must the rain have on the soil, in countries where nearly as much falls in a month, as in England during the course of a whole year;*—where every thing soluble is speedily washed from the land, and nothing seems to be left but a mixture of sand and gravel? It may indeed be said with truth, that no department of natural science is incapable of yielding instruction—that scarcely any knowledge is superfluous—to the tiller of the soil.

It is thus that all branches of human knowledge are bound together, and all the arts of life, and all the cultivators of them, mutually dependent. And it is by lending each a helping hand to the others, that the success of all is to be secured and accelerated; while with the general progress of the whole the advance of each individual is made sure.

The recent contributions and suggestions of geology are the best proof of the readiness of the sciences of observation to give their aid to the promotion especially of agricultural knowledge. The geologist can best explain the immediate origin of your several soils, the cause of the diversities which even in the same farm, it may be in the same field, they not unfrequently exhibit;† the nature and differences among your subsoils, and the advantages you may expect from breaking them up or bringing them to the surface.

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* At Canton, in the month of May, the fall of rain is often as much as 20 inches.

† I cannot refer to a plainer, more simple, or more beautiful illustration of this fact than that which is presented in a short paper by Sir John Johnstone, Bart., inserted in the Journal of the English Agricultural Society, I. p. 271, entitled "On the Application of Geology to Agriculture." See also an able paper by the Rev. Mr. Thorpe, of which a valuable report is contained in the Doncaster Chronicle of December 5th, and which will be published in the proceedings of the Geological and Polytechnic Society of the West Riding of Yorkshire.

Geology is essentially a popular science, and the talents of its eminent English cultivators are admirably fitted to make it still more so. Hence, a certain amount of knowledge of this science has been of late years very generally diffused, and its relations to agriculture are becoming every day better understood. The Highland Society of Scotland, among its many other useful exertions, has done very much to connect agriculture and geology with the sphere of its own labours, while the Journal of the Royal Agricultural Society of England manifests a similar desire on the part of that numerous and talented body, to illustrate the connection of agriculture with geology and chemistry, in the southern division of the island. That Dr. Buckland, Mr. Murchison, and Mr. De la Beche have each engaged to make a gratuitous survey of the subsoils in several extensive agricultural districts, at the request of the Council of this Society,* shows that, where their services are estimated, our most eminent scientific men will not hesitate to devote them to the development of the most important branches of national industry.

The time, therefore, is peculiarly favourable for the increase and diffusion of agricultural knowledge. The growth of our population requires it—practical men are anxious to receive instruction—scientific men are eager to impart what they know, and to make new researches for the purpose of clearing up what is unknown—are we not justified, therefore, in anticipating hereafter a constant and general diffusion of light, a steady progress of agricultural improvement?

Having thus glanced at the state and prospects of scientific agriculture in general, and especially of the art of culture in England, permit me to advert to a few of those questions of daily occurrence among you, to which chemistry alone can give a satisfactory answer. I shall not in this place allude to the subject of manures—which form alone an entire chapter of most recondite chemistry, and which I shall take up in its proper place, but I shall select a few isolated topics, the bearing of chemical knowledge upon which is sufficiently striking.

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* Journal of the Royal Agricultural Society, Report of their Council, I. p. 188.

To form a just idea of the value and importance of such surveys, it is only necessary to read chap. xv., pp. 463 to 480, of Mr. De la Beche's "Geological Report on Cornwall and Devon," or Professor Hitchcock's "Report on a re-examination of the Economic Geology of Massachusetts."

Some soils are naturally barren, but how few of our agriculturists are able, in regard to such soils generally, to say why; how few who possess the knowledge requisite for discovering the cause! Of these barren lands some may be improved so as amply to repay the outlay; some, from their locality or from other causes, are in the present state of our knowledge irreclaimable. How important to be able to distinguish between these two cases!

Some apparently good soils are yet barren in a high degree. In endeavouring to improve such soils, practical men have no general rule—they can have none. They work in the dark—like a man who makes experiments in a laboratory, without a teacher or without a book, till, after many blunders and much expense, he discovers some fact, to himself new, but to others long known, and forming only one of many analogous facts, flowing from a common, and probably well-understood, principle.

"The application of chemical tests to such a soil," says Sir Humphry Davy, "is obvious. It must contain some noxious principle,* which may be easily discovered and probably easily destroyed. Are any of the salts of iron present, they may be decomposed by lime. Is there an excess of siliceous sand, the system of improvement must depend on the application of clay and calcareous matters. Is there a defect of calcareous matter, the remedy is obvious. Is an excess of vegetable matter indicated, it may be removed by liming, paring, and burning. Is there a deficiency of vegetable matter, it is to be supplied by manure."†

What was true in regard to the applications of chemistry in the time of Sir Humphry Davy is more true in a high degree of the chemistry of our time. Not only is the nature of soils better understood, but we know in many cases what a soil *must* contain before it will produce a given crop. Why do pine forests settle themselves on the naked and apparently barren rocks of Scotland and of Northern Europe, content if their young roots can find but a crevice in the mountain to shelter them? Why does the beech luxuriate in the alluvial soils of Southern Sweden, of Zealand, and Continental Denmark? Why does the birch spring up from the ashes of the pine forest—why the rapid rush of delicate grass from the burned prairies of India and of Northern America? Whence comes the thick and tender sward of the mountain limestone districts—whence the gigantic wheat stalk of a virgin soil? Why do the same forest trees propagate themselves for ages on the same spots without impoverishing the soil—why do the natural grasses, the longer they are undisturbed, render the land only the more fertile?

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* Or be deficient in some necessary element.—J.

† Agricultural Chemistry, Lecture I.

These, one would think, are scarcely chemical questions, and yet to all of them, and to a thousand such, chemistry alone can and will give a satisfactory answer.

The rotation of crops is a practical rule, the benefit of which has been proved by experience; it becomes a true philosophical principle of action, when we discover the causes from which this benefit springs. Botany has thrown considerable light, and of an interesting and important kind, upon this practice, but chemistry has fully cleared it up and established the principle.

Sir Humphry Davy speaks of the use of lime. Can you explain the mysterious, and apparently fickle and diversified, agency of this substance in reference to vegetation? Are the advantages so frequently attendant upon its use to be ascribed to the chemical character of the soil to which it is applied, to the kind and quantity of the vegetable matter it contains, or to the geological nature of the rocks on which it rests? Are they dependent upon the drainage and exposure of the land—on the kind of crop to be raised—on the general climate of the district—on the maxima and minima of temperature—or on the quantity of rain which falls?

So with gypsum. Why are its effects lauded in one district, doubted in another, and decried in a third! Are no rules or principles to be discovered, by which these diversified effects are to be explained, and the true purpose and fit use of these and other mineral substances clearly pointed out? Such principles are yet to be sought for; but if sought by the way of well devised and accurately conducted experiment, they are *sure* to be discovered.

The land is exhausted by frequent cropping. What language more familiar, what statement more true than this? Yet how few understand what exhaustion implies; how few can explain either how it takes place, by what means it can be remedied, or how, if left to herself, nature at length does apply a remedy!

Have you any doubt in regard to the prevailing ignorance on this subject? To be satisfied, you have only to look with an experienced eye on the agricultural practice of the county of Durham. Are there not thousands of acres in the centre of this county which exhibit a degree of unproductiveness not natural to the soil;—which have been overcropped, and worn out, and impoverished? A soil comparatively fertile by nature has been rendered unfertile by art. That which was naturally good has been rendered as unproductive and unprofitable as that which was naturally bad. Has this state of things arisen from ignorance, from design, or from necessity? By whichever of these it has been immediately caused, it is clear that the requisite degree of knowledge on the part of the owners of the soil would have retarded if not wholly prevented it.

The same knowledge will enable them to reclaim these lands again, and gradually restore them to a more fertile condition; for the changes which the soil undergoes in such circumstances are all chemical changes,—either in the relative quantities of the substances it contains, or in the state of combination in which they exist.

The art of culture indeed is almost entirely a chemical art, since nearly all its processes are to be explained only on chemical principles. If you add lime or gypsum to your land, you introduce new chemical agents. If you irrigate your meadows, you must demand a reason from the chemist for the abundant growth of grass which follows. Do you find animal manure powerful in its action, is the effect of some permanent, while that of others is speedily exhausted?—does a mixture of animal and vegetable manure prepare the land best for certain kinds of grain?—do you employ common salt, or gypsum, or saltpetre, or nitrate of soda, with advantage?—in all these cases you observe chemical results which you would be able to control and modify did you possess the requisite chemical knowledge.

It is not wonderful that even theoretical agriculturists should be far behind in the knowledge of those principles on which their most important operations depend. The greatest light has been thrown upon the art of culture by the researches of organic chemistry, a branch which may be said to have started, if not into existence, at least into a new life, within the last ten years. Every day too is adding to the number and value of its discoveries, and the agriculturist may well be pardoned for not keeping pace with the advances of a department of science, which even the professed and devoted chemist can scarcely overtake.

I might advert also to the mechanical operations of ploughing, whether common or subsoil, of fallowing, draining, weeding, and many others, as being only so many methods by which chemical action is induced or facilitated;—to the growth of plants, and even to such observed differences as that of the relative quantity of leaves and tubers in the potatoe, and of grain and straw in our corn-fields, as interesting cases on which scientific chemistry throws a flood of light. I might shew how the feeding of your cattle and the raising and management of dairy produce are not beyond the province of chemistry, but that the only approach to scientific principle yet made, even in these branches of husbandry, is derived from the results of chemical research.

But I do not dwell on any of these points: they will all hereafter come under our review in their appropriate order, and will afford me an opportunity of laying before you many important facts, as well as, I hope, valuable practical deductions and observations.

While, however, I feel justified in saying thus much of the light which existing chemical knowledge throws on the natural processes of vegetation, and on the artificial methods of practical agriculture, I would not lead you to suppose that our knowledge is by any means complete, that there are not many points over which much darkness still rests—that some of the theoretical views now entertained are not crude, adopted too hastily, and generalized too rapidly. But a similar confession may be made in reference to all the modern sciences of observation without diminishing their importance or detracting from the value of the facts they embody. Human science is progressive in all its branches, and to refuse to follow the indications of existing knowledge because it is to some extent uncertain, would be as foolish as to refuse to avail ourselves of the morning's light, because it is not equal to that of the midday sun.

I advance, therefore, to the special object of these lectures, and I shall first present you with a rapid outline of the method which I intend to follow. It is indispensable that this method should be simple, and that every consecutive portion should be so fitted to clear the way for, and throw light upon, what is to follow, that we may be able to advance from the first rudiments to the most difficult and abstruse parts of our subject, without any chance of the illustrations being even difficult to comprehend. This end I do not hope perfectly to attain, but it will be my constant aim, and, with due attention on your part, I do not fear that we shall fail in arriving at a perfect understanding of the various points to which I shall have occasion to direct your attention.

I propose, therefore, to bring before you—

I. The constitution of vegetable substances, with the properties of the elementary and compound bodies which either enter into the substances of plants, or contribute to their growth and nourishment.

II. The general structure and functions of the several parts of plants—their mode of growth—and the manner in which their food is absorbed, changed, and converted into parts of their substance.

III. The origin, nature, and principal differences of soils—with the circumstances on which their relative fertility depends, or under which it is modified.

IV. The nature and differences of manures, and their mode of action, whether directly in supplying food to the plant, or indirectly in hastening and increasing their growth.

V. The nature and diversities of the food raised as the result of culture—especially in reference to their several equivalents or powers of supporting animal life.

Under this head the feeding of cattle, and the variations in the quantity and quality of dairy produce, will form subjects of consideration.

These different branches, I believe, comprehend the whole subject of chemical agriculture; in regard to all of them we shall derive either from chemistry or geology much important information.

§ 1. *Different kinds and states of Matter.*

All the forms of matter which present themselves to our view, whether in the solid crust of the globe on which we live, in the air which forms the atmosphere by which we are surrounded, or in the bodies of animals and plants—all are capable of being divided into the two great groups of organic and inorganic matter. The solid rocks and soils, the atmosphere, the waters of the seas and oceans, every thing which neither is nor has been the seat of life, may generally be included under the head of inorganic matter. The bodies of all living animals and plants, and their dead carcases, consist of organic or organized matter. These generally exhibit a kind of structure readily visible by the eye, as in the pores of wood, and in the fibres of hemp, or of the lean of beef,* and are thus readily distinguished from inorganic matter, in which no such structure is observable.

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* The pores of wood and fibres and minute vessels in animals being the *organs* or instruments of life, the substances themselves are called organized or organic.

But in many substances of organic origin also, no structure is observable. Thus, sugar, starch, and gum, are formed in plants in great abundance, and yet do not present any pores or fibres; they have never been endowed with organs, yet being produced by the *agency* of living organs, they are included under the general name of organic matter. So when animals and plants die, their bodies undergo decay, but the matter of which they are composed is considered as of organic origin, not only as long as any traces of structure are observable, but even after all such traces have disappeared. Thus coal is a substance of organic origin, though almost all traces of the vegetable matter from which it has been derived, have been long ago obliterated.

Again, heat chars and destroys wood, starch, and gum, forming black substances totally unlike the original matter acted upon. By distillation, wood yields tar and vinegar; and by fermentation, sugar is converted first into alcohol, and then into vinegar. All substances derived from vegetable or animal products by these and similar processes are included under the general designation of organic bodies.

Now if we take a portion of almost any of those numerous forms of matter which we meet with either in the inorganic or in the organic kingdoms, we find, that on subjecting it to certain chemical processes, it is capable of being resolved or separated into more than one substance. Thus coal when put into a gas retort is resolved into tar, coal gas, and certain other substances. Wood, when treated in the same way, yields pyroligneous acid, tar, and water, and leaves behind a residue of charcoal. If again we subject charcoal to the action of heat (not in the open air), or to any other process we can devise, we can never separate any thing further from it. After all our operations we obtain only charcoal.

So a piece of common lead ore, when heated in a similar manner, will, if pure, give off sulphur only, and leave the lead behind, from which nothing but lead can afterwards be extracted.

Thus it is evident that wood and the ore of lead differ from charcoal and metallic lead in this respect, that the former consist of more than one kind of matter, the latter of one kind of matter only. Hence charcoal and lead are called *simple* or *elementary* bodies, while wood and all other substances which are capable of being resolved into two or more different kinds of matter are called *compound* bodies.

The diversified forms of matter which present themselves to our notice in the mineral crust of the globe, and in the organs and vessels of plants and animals, are absolutely without number. We can no more reckon them than we can the stars of heaven. Yet it is one of those results of modern chemistry which to the mind not yet familiarized with chemical discoveries appears most wonderful,—that these numberless forms of matter are capable of being resolved into, and therefore are composed or made up of, only 55* of those simple or elementary substances, the nature of which has been above explained. Occasionally these elementary substances occur in a separate state, as in native† gold and silver, but they are generally found associated together, forming substances from which several of the 55 simple bodies may be extracted.

All the material substances in nature consist of one or more of these 55 elementary bodies. This is sufficiently surprising, yet it is, if possible, still more remarkable that nearly the entire mass of every vegetable substance may be resolved into one or more of *four* only of these simple substances.

When a portion of animal or vegetable matter is burned it either entirely disappears or leaves behind it only a small quantity of ash. Animal and vegetable oils and fats, gum, sugar, and starch, when burned, disappear entirely ; a piece of wood or of lean meat leaves a small quantity of earthy (inorganic) matter behind.

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* The names of these elementary bodies are as follows:—Oxygen, hydrogen, nitrogen, sulphur, selenium, phosphorus, chlorine, bromine, iodine, fluorine, carbon, boron, silicon, potassium, sodium, lithium, barium, strontium, calcium, magnesium, aluminium, glucinium, yttrium, zirconium, thorium, cerium, lanthanium, manganese, iron, cobalt, nickel, zinc, cadmium, lead, tin, bismuth, copper, uranium, mercury (quicksilver), silver, palladium, iridium, platinum, gold, osmium, titanium, tantalum (columbium), tungsten, molybdenum, vanadium, chromium, antimony, tellurium, arsenic.

† So called when found in the malleable state.

Now all that disappears when any portion of vegetable matter, of any kind, is burned, consists generally of three, and only in some rare cases of more than four, of the elementary bodies. These four are carbon, oxygen, hydrogen, and nitrogen. With the exception of the matter indestructible by fire (the ash), chemical analysis* has hitherto failed to detect the presence, in any notable quantity, of more than these four substances. The same remarks apply with almost equal truth to animal substances. The destructible part of these also consists of the same four elements.

To the agriculturist, therefore, an acquaintance with these four constituent parts of all that lives and grows on the face of the globe is indispensable. It is impossible for him to comprehend the laws by which the operations of nature in the vegetable kingdom are conducted, nor the reason of the processes he himself adopts in order to facilitate or to modify these operations, without this previous knowledge of the nature of the elements—the raw materials as it were—out of which all the products of vegetable growth are elaborated.

I shall first, therefore, exhibit to you briefly the properties of these *organic* constituents of plants, in order that we may be prepared for the further inquiries—by what means or in what form they enter into the circulation of plants—and how, when they have so entered, they are converted into those substances of which the skeleton of the plant consists or which are produced in its several organs.

§ 2. *Carbon—its properties and relations to vegetable life.*

Carbon is the name given by chemists to the substance of wood charcoal in its purest form. When wood is distilled in close vessels, or burned in heaps covered over, so as to prevent the free access of air, wood charcoal is left behind. When this process is well performed, the charcoal consists of carbon with a slight admixture only of earthy and saline matters, which remain behind on burning the charcoal in the air.

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* Under the general name of chemical *analysis* are comprehended the various processes by which, as above explained, natural forms of matter may be resolved or separated into the several *elements* or simple substances of which they consist.

Heated in the air, charcoal burns with little flame, and, with the exception of the ash which is left, entirely disappears. It is converted into a kind of air known among chemists by the name of carbonic acid, which ascends as it is formed and mingles with the atmosphere.

Charcoal is light and porous, and floats upon water, but plumbago or black lead and the diamond, which are only other forms of carbon, are heavy and dense. The former is 2½, and the latter 3½, times heavier than water. The diamond is the purest form of carbon, and at a high temperature it burns in the air or in oxygen gas, and, like charcoal, disappears in the state of carbonic acid gas.

Of this carbon all vegetable substances contain a very large portion. It forms from 40 to 50 per cent., by weight, of all the parts of plants which are cultivated for the food of animals or of man.* In the economy of nature, therefore, it performs a most important part.

The light porous charcoals obtained from wood† and from animal substances possess several interesting properties, which are of practical application in the art of culture. 1°. They have the power of absorbing in large quantity into their pores, the gaseous substances and vapours which exist in the atmosphere ;‡ and on this property, as I shall explain hereafter, the use of charcoal powder as a manure probably in some measure depends. 2°. They also separate from water any decayed animal matters or colouring substances which it may hold in solution ; hence its use in filters for purifying and sweetening impure river or spring waters, or for clarifying syrups and oils. This action is so powerful that port wine is rendered perfectly colourless by filtering through a well prepared charcoal.

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* That is, of these plants in their *dried* state.

† Especially from the willow, the pine, and the box.

‡ Thus of ammonia they absorb 95 times their own bulk, of sulphuretted hydrogen 55 times, of oxygen 9 times, of hydrogen nearly twice their bulk, and of aqueous vapour so much as to increase their weight from 10 to 20 per cent.

In or upon the soil charcoal for a time will act in the same manner, will absorb from the air moisture and gaseous substances, and from the rain and from flowing waters organized matters of various kinds, any of which it will be in a condition to yield to the plants which grow around it, when they are such as are likely to contribute to their growth.

3°. They have the property also of absorbing disagreeable odours in a very remarkable manner. Hence animal food keeps longer sweet when placed in contact with charcoal—hence also vegetable substances containing much water, such as potatoes, are more completely preserved by the aid of a quantity of charcoal—and hence the refuse charcoal of the sugar refiners is found to deprive night-soil of its disagreeable odour, and to convert it into a dry and portable manure. 4°. They exhibit also the still more singular property of extracting from water a portion of the saline substances they may happen to hold in solution, and thus allowing it to escape in a less impure form. The decayed (half carbonized) roots of grass, which have been long subjected to irrigation, may act in one or all of these ways on the more or less impure water by which they are irrigated—and thus gradually arrest and collect the materials which are fitted to promote the growth of the coming crop.

§ 3. *Oxygen—its properties and relations to vegetable life.*

Oxygen is a substance with which we are acquainted only in the gaseous or aeriform state.* By the unaided senses it cannot be distinguished from common air, being void of colour, taste and smell. But if a lighted taper be plunged into it, the flame is wonderfully increased both in size and brilliancy, and the taper burns away with great rapidity.

The effect of this gas upon animal life is of a similar kind. When a living animal is introduced into a large vessel filled with oxygen, the rapidity of the circulation is increased, all the vital functions are stimulated and excited, a state of fever comes on, and after a time the animal dies.

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* In this state it is readily obtained by heating in a glass retort the red oxide of mercury of the shops, or a white salt known by the name of chlorate of potash.

By these two characters, oxygen is distinguished from every other elementary body. It exists in the atmosphere to the amount of 21 per cent. of its bulk, and in this state of air is necessary to the existence of animals and of plants, and to the support of combustion on the face of the globe. It exists also largely in water, every nine pounds of this liquid containing eight pounds of oxygen.

But the quantity of this substance which is stored up in the solid rocks is still more remarkable. Nearly one-half of the weight of the solid rocks which compose the crust of our globe, of every solid substance we see around us—of the houses in which we live, and of the stones on which we tread—of the soils which you daily cultivate, and much more than one-half by weight of the bodies of all living animals and plants, consist of this elementary body oxygen, known to us, as I have already said, only in the state of a gas. It may not appear surprising that any one elementary substance should have been formed by the Creator in such abundance as to constitute nearly one-half by weight of the entire crust of our globe, but it must strike you as remarkable, that this should also be the element on the presence of which all animal life depends—and as nothing less than wonderful, that a substance which we know only in the state of thin air, should, by some wonderful mechanism, be bound up and imprisoned in such vast stores in the solid mountains of the globe, be destined to pervade and refresh all nature in the form of water, and to beautify and adorn the earth in the solid parts of animals and plants. But all nature is full of similar wonders, and every step you advance in the study of the principles of the art by which you live, you will not fail to mark the united skill and bounty of the same great Contriver.

Oxygen gas is heaver than common air in the proportion of about 11 to 10;* it is also capable of being absorbed by water to a certain extent. One hundred measures of water dissolve 6½[*] of this gas. Rain, spring, and river waters, always contain a portion of oxygen which they have derived from the atmosphere, and this oxygen as they trickle through the soil, ministers to the growth and nourishment of plants in various ways. Some of these will be explained in a subsequent lecture.

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* Its specific gravity by experiment is 1·1026, air being 1.

In an atmosphere of pure oxygen gas, plants refuse to vegetate and speedily perish.

§ 4. *Hydrogen—its properties and relations to vegetable life.*

Hydrogen is also known to us only in the state of gas, and when perfectly pure agrees with oxygen and common air in being without colour, taste, or smell, It is not known to occur in nature in a free or simple state, nor does it exist so abundantly as either carbon or oxygen. It forms a small per centage of the weight of all animal and vegetable substances, and constitutes one-ninth of the weight of water, but with the exception of coal, it does not enter as a constituent into any of the large mineral masses that exist in the crust of the globe.

When a lighted taper is plunged into this gas it is immediately extinguished, but if in contact with the air the gas itself takes fire and burns with a pale yellow flame. If previously mixed with air or with oxygen gas, it kindles and burns with a loud explosion. During this combustion water is formed.[†]

It does not support life, animals cease to breathe when introduced into it, and plants gradually wither and die. It is the lightest of all known substances, being about 14½ times lighter than common air,[‡] so that if the stopper be removed from a bottle in which it is contained it almost immediately escapes. It is the element which is employed to give buoyancy to balloons; and by this great levity and its relations to flame it is readily distinguished from all other known substances.

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[*] De Saussure. According to Dr. Henry, 100 volumes of water absorb only 3½ of oxygen.

[†] See the Second Lecture.

[‡] Its specific gravity, by experiment, is 0·0687, air being 1.

Water absorbs it only in very small quantities, 100 gallons taking up no more than about 1½ gallons of hydrogen gas. But, as already observed, this gas does not exist in nature in a free state—is not necessary, therefore, to the growth of plants or animals in this state—and hence its insolubility in water is in unison with the general adaptation of every property of every body, to the health and growth of the highest orders of living beings.

Hydrogen gas is readily obtained from water by putting into it a few pieces of metallic iron or zinc, and adding a little sulphuric acid (oil of vitriol). Bubbles of the gas are liberated from the surface of the metal, ascend through the water, and may be collected on the surface.

§ 5. *Nitrogen—its properties and relations to vegetable life.*

Nitrogen is also known to us only in the form of gas. It exists in the atmosphere to the amount of 79 per cent. of its bulk. It is without colour, taste, or smell. Animals and plants die in this gas, and a taper is instantly extinguished when introduced into it; the gas itself undergoing no change. It is lighter than atmospheric air, in the proportion of 97½ to 100.* It is an essential constituent of the air we breathe, serving to temper the ardour with which combustion would proceed and animals live in undiluted oxygen gas. It forms a part of very many animal and of some vegetable substances, but it is not known to enter into the composition of any of the great mineral masses of which the earth's crust is made up. In coal alone, which is of vegetable origin, it has been detected to the amount of one or two per cent. It is therefore much less abundant in nature than any of the other so called organic elements—and it exhibits much less decided properties than any of them; yet we shall hereafter see that it performs certain most important functions in reference both to the growth of plants and to the nourishment of animals.

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* Its density is 0·976, air being 1.

One hundred volumes of water dissolve about 1½ volumes of this gas.* Spring and rain waters absorb it as they do oxygen, from the atmospheric air, and bear it in solution to the roots, by which it is not unlikely that it may be conveyed directly into the circulation of plants.

Such are the several elementary bodies of which the organic or destructible part of vegetable substances is formed. With one exception they are known to us only in the form of gases; and yet out of these gases much of the solid parts of animals and of plants are made up. When alone, at the ordinary temperature of the atmosphere they form invisible kinds of air; when united, they constitute those various forms of vegetable matter which it is the aim and end of the art of culture to raise with rapidity, with certainty, and in abundance. How difficult to understand the intricate processes by which nature works up these raw materials into her many beautiful productions—yet how interesting it must be to know her ways, how useful even partially to find them out!

Permit me, in conclusion, to submit to you one reflection. We have seen that oxygen, hydrogen, and nitrogen, are all gaseous substances, which when pure are destitute of colour, taste, and smell. They cannot be distinguished by the aid of our senses. Man in a state of nature—uneducated man—cannot discern that they are different. Yet so simple an instrument as a lighted taper at once shows them to be totally unlike each other. This simple instrument, therefore, serves us instead of a new sense, and makes us acquainted with properties the existence of which, without such aid, we should not even have suspected. Has the Deity then been unkind to man, or stinted in his benevolence in withholding the gift of such a sense. On the contrary, he has given us an understanding which when cultivated is better than twenty new senses. The chemist in his laboratory is better armed for the investigation of nature, than if his organs of sense had been many times multiplied. He has many instruments at his command, each of which, like the taper, tells him of properties which neither his senses nor any other of his instruments can discover; and the further his researches are carried, the more willing does nature seem to reveal her secrets to him, and the more rapidly do his chemical senses increase. Do you think that the rewards of study and patient experimental research are confined to the laboratory of the chemist, and that the Deity will prove less kind to you, whose daily toil is in the great laboratory of nature? As yet you see but faintly the reason of many of your commonest operations, and over the results you have comparatively little control—but the light is ready to spring up, the means are within your reach—you have only to employ your minds as diligently as you labour with your hands, and ultimate success is sure.

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* Henry De Saussure says, that pure water absorbs 4 per cent. of its bulk of this gas.

LECTURE II.

Characteristic properties of organic substances—Relative proportions of organic elements—Variable proportions of inorganic elements in plants—Form in which the organic elements are taken up by plants—The atmosphere, its constitution and relations to vegetable life—Nature and laws of chemical combination—Water and its relations to vegetable life.

§ 1. *Characteristic properties of organic substances.*

Of the four elementary substances described in the former lecture, the organic part of all animal and vegetable substances consists. What is understood by the term organic has also been explained.

But organic substances possess certain characters by which they are distinguished from the inorganic or dead matter of the globe, and on which their connection with the principle of life, and with the art of culture, entirely depends. These characteristic properties are chiefly the following:

1°. They are all easily decomposed or destroyed by a moderately high temperature. If wood or straw be heated in the air, as over the flame of a candle, it becomes charred, burns, and is in a great measure dissipated. So sugar and starch darken in colour when heated, blacken, and take fire. The same is true of all vegetable substances. But limestone, clay, and other earthy or stony matters, undergo no apparent change in such circumstances—they are not decomposed.

2°. When exposed to the air, especially if it be warm and moist, vegetable and animal substances putrify and decay.* They decompose of their own accord, and after a time almost entirely disappear. Such is not the case with inorganic matters. If the rocks and stones crumble, their particles may be washed away by the rains to a lower level, but they never putrify or wholly disappear.

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* For an explanation of the exact nature and end of this putrefaction, see the subsequent Lecture, "*On the decay of animal and vegetable substances.*"

3°. They consist almost entirely of two or more of the four organic elements only. The mineral substances we meet with on the earth's surface, and collect for our cabinets, often contain portions of many elementary bodies; but, with few exceptions, the organic part of all plants, that which lives and grows, contains only the four simple substances described in my former lecture.

4°. They are distinguished also by this important character, that they cannot be formed by human art. Many of the inorganic compounds which occur in the mineral crust of the globe can be produced by the chemist in his laboratory, and were any corresponding benefit likely to be derived from the expenditure of time and labour, there is reason to believe that, with a few exceptions, nature might be imitated in the formation of any of her mineral productions. But in regard to organic substances, whether animal or vegetable, the chemist is perfectly at fault. He can form neither woody fibre, nor sugar, nor starch, nor muscular fibre, nor any of those substances which constitute the chief bulk of animals and plants, and which serve for the food of animated beings. This is an important and striking, and is, I believe, likely to remain a permanent distinction, between most substances of organic and of inorganic origin.

Looking back at the vast strides which organic chemistry has made within the last twenty years, and is still continuing to make, and trusting to the continued progress of human discovery, some sanguine chemists venture to anticipate the time when the art of man shall not only acquire a dominion over that principle of life, by the agency of which plants now grow and alone produce food for man and beast, but shall be able also, in many cases, to imitate or dispense with the operations of that principle; and to predict that the time will come when man shall manufacture by art those necessaries and luxuries for which he is now wholly dependent on the vegetable kingdom.

And, having conquered the winds and the waves by the agency of steam, is man really destined to gain a victory over the uncertain seasons too? Shall he come at last to tread the soil beneath his feet as a really useless thing—to disregard the genial shower, to despise the influence of the balmy dew—to be indifferent alike to rain and drought, to cloud and to sunshine—to laugh at the thousand cares of the husbandman—to pity the useless toil and the sleepless anxieties of the ancient tillers of the soil? Is the order of nature, through all past time, to be reversed—are the entire constitution of society, and the habits and pursuits of the whole human race, to be completely altered by the progress of scientific knowledge?

By placing before man so many incitements to the pursuit of knowledge, the will of the Deity is, that out of this increase of wisdom he should extract the means of increased happiness and enjoyment also. But set man free from the necessity of tilling the earth by the sweat of his brow, and you take from him at the same time the calm and tranquil pleasures of a country life—the innocent enjoyments of the returning seasons—the cheerful health and happiness that wait upon labour in the free air and beneath the bright sun of heaven. And for what?—only to imprison him in manufactories, to condemn him to the fretful and feverish life of crowded cities.

To such ends, I trust, science is not destined to lead; and he is not only unreasonably, but thoughtlessly sanguine, who would hope to derive from organic chemistry such power over dead matter as to be able to fashion it into food for living animals. With such consequences before us it seems almost sinful to wish for it.

Yet, that this branch of science will lead to great ameliorations in the art of culture, there is every reason to believe. It will explain old methods—it will clear up anomalies, reconcile contradictory results by explaining the principles from which they flow—and will suggest new methods by which better, speedier, or more certain harvests may be reaped.

§ 2. *Relative proportions of organic elements.*

Though the substance of plants consists chiefly of the four organic elements, yet these bodies enter into the constitution of vegetables in very different proportions. This fact has already been adverted to in a general manner: it will appear more distinctly by the following statement of the exact quantities of each element contained in 1000 parts by weight of some of the more important kinds of vegetable substances you are in the habit of cultivating:—

	Hay from young Clover 3 months old.	Oats.	Clover Seed.	After-math Hay.	Peas.	Wheat.	Hay.	Potatoes.
Carbon . .	507	507	494	471	465	455	458	441
Hydrogen.	66	64	58	56	61	57	50	58
Oxygen . .	389	367	350	349	401	431	387	439
Nitrogen .	38	22	70	24	42	34	15	12
Ash	not stated	40	28	100	31	23	90	50
	1000[*]	1000[†]	1000[*]	1000[†]	1000[‡]	1000[*]	1000[†]	1000[†]

The numbers in the above table represent the constitution of the plants and seeds, taken in the state in which they are given to cattle or are laid up for preservation, and then dried at 230° Fahrenheit. By this drying they lost severally as follows:

1000 parts of Potatoes. . . . lost . . . . 722 parts of water.
ditto of Wheat . . . . — . . . . 166 ditto.
ditto of Hay. . . . . . — . . . . 158 ditto.
ditto of Aftermath Hay — 136 to 140 ditto.
ditto of Oats. . . . . . — . . . . 151 ditto.
ditto of Clover Seed. . — . . . . 112 ditto.
ditto of Peas . . . . . — . . . . 86 ditto.

In crops as they are reaped, therefore, and even as they are given for food, much water is present. When artificially dried, the carbon approaches to one-half of their

[*] Boussingault Annales de Chim. et de Phys. (1838) LXVII. p. 20 to 38.
[†] Ditto Ibid (1839) LXXI. p. 113 to 136.
[‡] Ditto Ibid (1838) LXIX. p. 356.

weight—the oxygen to more than one-third*—the hydrogen to little more than 5 per cent. and the nitrogen rarely to more than 2½ per cent. These proportions are variable, but they represent very nearly the relative weights in which these elements enter into the constitution of those forms of vegetable matter which are raised in the greatest quantity for the support of animal life.

But, besides the organic part, vegetable substances contain an inorganic portion, which remains behind in the form of ash when the plant is consumed by fire, or of dust when it decomposes and disappears in consequence of natural decay.

In the dried hay, oats, &c., of which the composition is represented in the above table, we see that the quantity of ash is very variable, in oats being as small as 4 per cent., while of hay every hundred pounds left 10 of ash. A similar difference is observed generally to prevail throughout the vegetable kingdom. Each variety of plant, when burned, leaves a weight of ash, more or less peculiar to itself. Herbaceous plants generally leave more than the wood of trees—and different parts of the same plant yield unlike quantities of inorganic matter.† These facts are of great importance in the theory and in the enlightened practice of agriculture. They will hereafter come under special and detailed consideration, when we shall have examined the nature of the soils in which plants grow, and shall be prepared to consider the chemical nature, the source, and the functions, of the inorganic compounds which exist in living animal and vegetable substances.

§ 3. *Of the form or state of combination in which the organic elements enter into and minister to the growth of plants.*

From the details already presented in the preceding Lecture, in regard to the properties of carbon and hydrogen, and the circumstances under which they are met with in nature,—it will readily occur to you that neither of these elementary bodies is likely to enter directly, or in a simple state, into the circulation of plants. The former (carbon) being a solid substance, and insoluble in water, cannot obtain admission into the pores of the roots, the only parts of the plants with which, in nature, it can come in contact. The latter (hydrogen) does not occur either in the atmosphere or in the soil in any appreciable quantity, and hence, in its simple state, forms no part of the food of plants. Oxygen and nitrogen, again, both exist in the atmosphere in the gaseous state, and the former is known to be inhaled, under certain conditions, by the leaves of plants. Nitrogen may also in like manner be absorbed by the leaves of living plants, but, if so, it is in a quantity so small as to have hitherto escaped detection. The two latter substances (oxygen and nitrogen) are also slightly soluble in water, and, besides being inhaled by the leaves, may occasionally be absorbed in minute quantity along with the water taken in by the roots. But by far the largest proportion of these two elementary bodies, and the whole of the carbon and hydrogen which find their way into the interior of plants, have previously entered into a state of mutual combination —forming what are called distinct chemical compounds. Before describing the nature and constitution of these compounds, it will be proper to explain, 1°. the constitution of the atmosphere in which plants live, and, 2°. the nature of chemical combination and the laws by which it is regulated.

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* This will appear no way inconsistent with the statement in the former Lecture, that oxygen constitutes one-half by weight of all *living* plants, when it is recollected that of the water driven off in drying these plants eight-ninths by weight consist of oxygen, and that 600lbs. of grass, for example, yield only from 80 to 100lbs. of hay.

† Thus of the oak, the dried bark left 60 of ash—the dried leaves 53—the dried alburnum 4—and the dried wood only 2 parts in a thousand of ash.—*De Saussure.*

§ 4. *On the constitution of the atmosphere.*

The air we breathe, and in which plants live, is composed principally of a mixture of oxygen and nitrogen gases, in the proportion very nearly of 21 of the former to 79 of the latter. It contains, however, as a constituent necessary to the very existence of vegetable life, a small per centage of carbonic acid. On an average this carbonic acid amounts to about $\frac{1}{2500}$th part* of the bulk of the air. On the shores of the sea, or of great lakes, this quantity diminishes; and it becomes sensibly less as we recede from the land. It is also less by day than by night (as 3·38 to 4·32), and over a moist than over a dry soil.

The air is also imbued with moisture. Watery vapour is every where diffused through it, but the quantity varies with the season of the year, with the climate, with the nature of the locality, with its altitude, and with its distance from the equator. In temperate climates, it oscillates on the same spot between ½ and 1½ per cent. of the weight of the air; being least in mid-winter and greatest in the hot months of summer. There are also mingled with the atmosphere, traces of the vast variety of substances which are capable of rising from the surface of the earth in the form of vapour: such, for example, as are given off by decaying animal or vegetable matter—which are the produce of disease in either class of bodies—or which are evolved during the operations of nature in the inorganic kingdom, or by the artificial processes of man. Among these accidental vapours are to be included those miasmata, which, in certain parts of the world, render whole districts unhealthy,—as well as certain compounds of ammonia, which are inferred to exist in the atmosphere, because they can be detected in rain water, or in snow which has newly fallen.

In this constitution of the atmosphere we can discover many beautiful adaptations to the wants and structure of animals and plants. The exciting effect of pure oxygen on the animal economy is diluted by the large admixture with nitrogen;—the quantity of carbonic acid present is sufficient to supply food to the plant, while it is not so great as to prove injurious to the animal;—and the watery vapour suffices to maintain the requisite moisture and flexibility of the parts of both orders of beings, without in general being in such a proportion as to prove hurtful to either.

The air also, by its subtlety, diffuses itself every where. Into every pore of the soil it makes its way. When there, it yields its oxygen or its carbonic acid to the dead vegetable matter or to the living root. A shower of rain expels the half-corrupted air, to be succeeded by a purer portion as the water retires. The heat of the sun warms the soil, and expands the imprisoned gases,—these partially escape, and are, as before, replaced by other air when the rays of the sun are withdrawn.

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* 0·04 per cent. The mean of 104 experiments made by Saussure at Geneva at all times of the year and of the day gave 4·15 volumes in 10000. The maximum was 5·74, and the minimum 3·15.

By the action of these and other causes a constant circulation is, to a certain extent, kept up,—between the atmosphere on the surface, which plays among the leaves and stems of plants, and the air which mingles with the soil and ministers to the roots. The precise effect and the importance of this provision will demand our consideration in a future lecture.

§ 5. *The nature and laws of chemical combination.*

The terms *combine* and *combination* in chemical language have a strict and precise application. If sand and saw-dust be rubbed together in a mortar they may be intimately intermingled, but by pouring water on the mass we can separate the particles of wood and leave the sand unchanged behind. So if we stir oatmeal and water together, we may cause them perfectly to mix together, but by the aid of a gentle heat we can expel the water and obtain dry oatmeal in its original condition. Or, by putting salt into water, it will dissolve and disappear, and form what is called a solution, but by boiling it down, as is done in our salt-pans, the water may be entirely removed and the salt procured of the weight originally employed and possessed of its original properties.

In none of these cases has any chemical action taken place, or any permanent change been produced, upon any of the substances. The two former were merely mixtures. *In all cases of chemical action a permanent change takes place in some of the substances employed*; and this change is the result either of a chemical *combination*, or of a chemical *decomposition*.

Thus when sulphur is burned in the air, it is converted into white vapours possessed of a powerful and very unpleasant odour, and which continue to be given off until the whole of the sulphur is dissipated.

Here a solid substance is permanently changed into noxious vapours which disappear in the air, and this change is caused by the combination of the sulphur with the oxygen of the atmosphere.

In like manner when limestone is put into a kiln and strongly heated or burned, it is changed or converted into quicklime—a substance very different in its properties from the natural limestone employed. But this is a case of chemical *decomposition*. The limestone consists of lime and carbonic acid. By the heat these are separated, the latter is driven off and the former remains in the kiln.

Again, when a jet of hydrogen gas is kindled in the air or in oxygen gas, it burns with a pale yellow flame. If a cold vessel be held over this flame, it speedily becomes bedewed with moisture, and drops of water collect upon it. How remarkable the change which hydrogen undergoes during this combustion! It unites with the oxygen of the atmosphere and forms water. How different in its properties is this water from either the oxygen or the hydrogen by the union of which it is formed! The former a liquid, the latter gases; the former an enemy to all combustion, while of the latter, the one (hydrogen) burns readily, the other (oxygen) is the very life and support of combustion in all other bodies.

1°. It appears, therefore, that chemical combination or decomposition is always attended by a permanent change.

2°. That when combination takes place a new substance is formed differing in its properties from any of those from which it was produced, or of which it consists.

When two or more elementary bodies thus unite together to form a new substance, this new substance is called a *chemical compound*. Thus water is a compound (not a mixture) of the two elementary bodies oxygen and hydrogen.

Now when such combination takes place, it is found to do so always in accordance with certain fixed laws. Thus:

I. Bodies unite together *only in constant and definite proportions*. We can *mix* together oxygen and hydrogen gases, for example, in any proportion, a gallon of the one with any number of gallons of the other, but if we burn two gallons of hydrogen gas in any greater number of gallons of oxygen, they will only consume or unite with one gallon of the oxygen, the rest of this gas remaining unchanged. A quantity of water will be formed by this union, in which the whole of the hydrogen will be contained, combined with all the oxygen that has disappeared. Under no circumstances can we burn hydrogen so as to cause it to consume more oxygen, or from a given weight of hydrogen to produce more than a known weight of water. And as oxygen is nearly sixteen times heavier than nitrogen, it is obvious that one gallon of the former is about eight times heavier than two gallons of the latter, so that by weight these two gases, when thus burned, unite together nearly in the proportion of 1 to 8,—one pound of hydrogen forming nine pounds of water.

Again, when pure carbon is burned in the air, it unites with a fixed and constant weight of oxygen to form carbonic acid; it never unites with more, and it does not form carbonic acid when it unites with less.

Now this law of fixed and definite proportions is found to hold in regard to all bodies, and in all cases of chemical combination. Thus we have seen that—

By weight.		*By weight.*	
1	of hydrogen combines with	8	of oxygen to form water.
So 6	of carbon combine	8	.... carbonic oxide.
and 14	of nitrogen	8	.... nitrous oxide.

Hence 1 of hydrogen, 6 of carbon, and 14 of nitrogen unite respectively with the weight (8) of oxygen. These several numbers, therefore, are said to be *equivalent* to each other (they are *equivalent numbers*). Or they represent the fixed and definite proportions in which these several substances combine together (they are *definite proportionals*). Some chemists consider these numbers to represent the relative weights of the atoms or smallest particles of which the several substances are made up, and hence not unfrequently speak of them as the *atomic weights* of these substances, or more shortly *their atoms*.

For the sake of brevity, it is often useful to represent the simple or elementary bodies shortly by the initial letter of their names. Thus hydrogen is represented by H, carbon by C, and nitrogen by N, and these letters are used to denote not only the substances themselves, but that quantity which is recognised as its *equivalent*, *proportional*, or *atomic weight.* Thus:

Symbol.	*Equivalent or atomic weights.*	*Name.*
H denotes	1 by weight, of	hydrogen.
C	6	carbon.
O	8	oxygen.
N	14*.	nitrogen.

Chemical *combination* is expressed shortly by placing these letters in juxta-position, or sometimes in brackets, with the sign plus (+) between them. Thus H O or (H + O) denotes the combination of one atom or equivalent of hydrogen with one of oxygen, that is water; and at the same time a weight of water (9), equal to the sum of the atomic weights (1 + 8) of hydrogen and nitrogen.

A number prefixed or appended to a symbol, denotes that so many equivalents of the substance represented by the symbol are meant, as that number expresses. Thus 2 H O, 3 H O, or 3 (H + O), mean two or three equivalents of water, 3 H or H^3 three equivalents of hydrogen, and 4 C or C^4, 2 N or N^2, four of carbon and two of nitrogen respectively.

II. Not only are the *quantities* of the substances which unite together definite and constant, but the *properties* or *qualities* of the substances formed are in general equally so. The properties of pure water or of carbonic acid are constant and invariable under whatever circumstances they may be formed, and the elements of which they consist, when they combine together in the same proportions, are never known to form any other compounds but water and carbonic acid.

This law, however, though generally, is not universally true. Many substances are known which contain the same elements united together in the same proportions, and which, nevertheless, possess very different properties. Oil of turpentine and oil of lemons are in this condition. They both consist of the same elements, carbon and hydrogen, united together in the same proportions, and yet their sensible properties as well as their chemical relations* are very dissimilar.

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* More correctly 1, 6·13, 8·013, and 14·19.

Cane sugar, starch, and gum, all of them abundant products of the vegetable kingdom, consist also of the same elements, carbon, hydrogen, and oxygen, united together in the same proportions, and may even be represented by the same *formula* ($C^{12}\ H^{10}\ O^{10}$),† and yet these substances are as unlike to each other in their properties, as many bodies are of which the chemical composition is very different. To compounds thus differing in their properties, and yet containing the same elements, in the same proportions, chemists have given the name of *Isomeric bodies.* I shall have occasion to make you more familiar with some of them hereafter.

3°. Another important law by which chemical combinations are regulated, is known by the name of the law of *multiple proportions.* Some substances are observed to be capable of uniting together in more than one proportion. Thus carbon unites with oxygen in several proportions, forming carbonic oxide, carbonic acid, oxalic acid, &c. Now when such is the case, it is found that the quantity (the weight) of each substance which enters into the several compounds, if not actually represented by the equivalent number or atomic weight, is represented by some simple multiple of that number. Thus two equivalents of carbon unite with 2, 3, or 4 equivalents of oxygen, to form carbonic oxide, oxalic acid, and carbonic acid respectively,—while one of nitrogen unites with 1, 2, 3, 4, or 5 of oxygen to form a series of compounds, of which the last ($N\ O^5$) nitric acid, is the only one I shall have frequent occasion to speak of in the present lectures.

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* By the chemical relations of a substance are meant the effects which are produced upon it by contact with other chemical substances.

† This *formula* means that starch, gum, and sugar, consist of 12 equivalents of carbon united to 10 of hydrogen and 10 of oxygen.

This law of multiple proportions, though of great importance in chemical theory, I do not further illustrate, as we shall have very little occasion to refer to it in the discussion of the several topics which will hereafter come before us.

Having thus briefly explained the nature and laws of chemical combination, I proceed to make you acquainted with those chemical compounds of the organic elements which are known or are supposed to minister to the growth of plants.

The number of compounds which the four organic elements form with each other is almost endless; but of this number a very few only are known to minister directly to the growth or nourishment of plants. Of these, water, carbonic acid, ammonia, and nitric acid, are the most important; but it will be necessary shortly to advert to a few others, of the occurrence or production or action of which we may hereafter have occasion to speak.

§ 6. *Of water and its relations to vegetable life.*

Water is a compound of oxygen and hydrogen in the proportion, as already stated, of 8 of the former to 1 of the latter by weight, or of 1 volume of oxygen to 2 of hydrogen.

It is more universally diffused throughout nature than any other chemical compound with which we are acquainted, performs most important functions in reference to animal and vegetable life, and is endowed with properties by which it is wonderfully adapted to the existing condition of things.

We are familiar with this substance in three several states of cohesion,—in the solid form as ice, in the fluid as water, and in the gaseous as steam. At 32° F. and at lower temperatures, it continues solid, at higher temperatures it melts and forms a liquid (water), which at 212° F. begins to boil and is converted into steam. By this change its bulk is increased 1700 times, and it becomes nearly two-fifths lighter than common air.* It therefore readily rises into and diffuses itself through the atmosphere.

I. There are only one or two circumstances in which water in the solid form materially affects or interferes with the labours of the agriculturist.

1°. During the frost of a severe winter, the soil contracts and appears to shrink in. But the water contained in its pores freezes and expands, and the minute crystals of ice thus formed separate the particles of the soil from each other. This expansion of the water in dry soils may not be equal to the natural contraction of the soil itself, yet still it is sufficient to cause a considerable separation of the earthy particles throughout the whole frozen mass. When a milder temperature returns, and a thaw commences, the soil expands and gradually returns to its former bulk; but the outer layers thaw first, and the particles being previously separated by the crystals of ice, and now loosened by the thaw, fall off or crumble down, and thus the soil becomes exposed to the mellowing action of the atmosphere, which is enabled everywhere to pervade it. On heavy clay land this effect of the winter's frost not unfrequently proves very beneficial.†

2°. In the form of snow it has been often supposed to be beneficial to winter wheat and other crops. That a heavy fall of snow will shelter and protect the soil and crop from the destructive effects of any severe cold which may follow, there can be no doubt. It forms a light porous covering, by which the escape of heat from the soil is almost entirely prevented. It defends the young shoots also from those alternations of temperature to which the periodical return of the sun's rays continually exposes them;* and when a thaw arrives, by slowly melting, it allows the tender herbage gradually to accustom itself to the milder atmosphere.

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* Common air being 1, steam is 0·62.

† This alternate contraction and expansion is often injurious to the practical farmer in *throwing out* his winter wheat. Some varieties are said to be more thrown out than others, and this peculiarity is sometimes ascribed to the longer and stronger roots which shoot from one variety than from another; it may, however, be occasionally owing to the different nature of the soils in which the trials have been made, or when, in the same soil, to the different states of dryness at different times.

In this manner there is no doubt that a fall of snow may often be of great service to the practical farmer. But some believe that winter wheat actually *thrives* under snow. On this point I cannot speak from personal knowledge, but I will here mention two facts concerning snow, which may possibly be connected with its supposed nourishing quality.

In the first place, snow generally contains a certain quantity of ammonia, or of animal matter which gives off ammonia during its decay. This quantity is variable, and is occasionally so small as to be very difficult of detection. Liebig found it in the snow of the neighbourhood of Giessen, and I have this winter detected traces of it in the snow which fell in Durham† during two separate storms. This ammonia is present in greater quantity in the first portions that fall and lie nearest the plant. Hence if the plant can grow beneath the snow, this ammonia may affect its growth; or when the first thaw comes it may descend to the root, and may there be imbibed. Rain water also contains ammonia, but when rain falls in large quantity it runs off the land, and may do less good than the snow, which lies and melts gradually.*

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* The effects of such alternations are seen on the occurrence of a night's frost in spring. If the sun's rays fall in the early morning, on a frozen shoot, it droops, withers, and blackens—it is destroyed by the frost. If the plant be in a shaded spot, where the sun does not reach it till after the whole atmosphere has been gradually heated, and the frozen tissue slowly thawed, its leaves sustain little injury, and the warmth of the sun's rays, instead of injuring, cherish and invigorate it. This effect of *sudden* alternations of temperature on organic matter explains many phenomena, to which it would here be out of place to advert.

A thick light covering of porous earth not beaten down preserves the potatoe pit from the effects of the frost better than a solid compact coating of clay, in the same way as snow protects the herbage better than a sheet of ice; and it is because of the porosity of the covering, that ice may be preserved more effectually, and for a longer period, in a similar pit, than in many well constructed ice-houses.

† By adding two drops of sulphuric acid to four pints of snow water,

Another singular property of snow is the power it possesses of absorbing oxygen and nitrogen from the atmosphere, in proportions very different from those in which they exist in the air. The atmosphere, as already stated, contains 21 per cent. of oxygen by volume (or bulk), but the air which is present in the pores of snow has been found by various observers to contain a much smaller quantity. Boussingault† obtained from air disengaged by melting snow 17 per cent. of oxygen only, and De Saussure found still less. The difficulty of respiration experienced on very high mountains has been attributed to the nature of the air liberated from snow when melted by the sun's rays. Whether the air retained among the pores of the snow, which in severe winters covers our corn-fields, be equally deficient in oxygen with that examined by Boussingault, and whether, if it be, the abundance of nitrogen can at all affect vegetation, are matters that still remain undetermined.

II. In the fluid state, that of water, the agency of this compound in reference to vegetable life, though occasionally obscure, is yet everywhere discernible.

Pure water is a colourless transparent fluid, destitute of either taste or smell. It enters largely into the constitution of all living animals and plants, and forms upwards of one half of the weight of all the newly gathered vegetable substances we are in the habit of cultivating or collecting for the use of man.‡

Not only does it enter thus largely into the constitution of all animals and plants, but in the existing economy of nature its presence in large quantities is absolutely necessary to the persistence of animal and vegetable life. In the midst of abundant springs and showers, plants shoot

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evaporating to dryness, and mixing the dry mass with quicklime or caustic potash. The residual mass contained a brown organic matter, mixed with the sulphate of ammonia.

* For the properties of ammonia, see Lecture III.

† Annalen der Physik (Poggendorf), xxxiv. p. 211.

‡ See page 33.

forth with an amazing rapidity, while they wither, droop, and die, when water is withheld. How much the manifestation of life is dependent upon its presence, is beautifully illustrated by some of the humbler tribes of plants. Certain mosses can be kept long in the herbarium, and yet will revive again when the dried specimens are immersed in water. At Manilla a species of Lycopodium grows upon the rocks, which, though kept for years in a dried state, revives and expands its foliage when placed in water.* Thus life lingers as it were, unwilling to depart and rejoicing to display itself again, when the moisture returns.†

There are, however, three special properties of water, which are in a high degree interesting and important to the practical agriculturist, and to which I beg to direct your particular attention. These are:

1°. Its solvent power;

2°. Its affinity for certain solid substances; and,

3°. The degree of affinity by which its own elements are held together.

1°. When pure boiled water is exposed to the air, it gradually absorbs a quantity of the several gases of which the atmosphere is composed, and acquires more or less of a sparkling appearance and an agreeable taste. The air which it thus absorbs amounts to about $\frac{1}{36}$th of its own bulk, and is entirely expelled by boiling. When thus expelled, this air, like that obtained from snow, is found on examination to contain the oxygen, nitrogen, and carbonic acid in proportions very different from those in which they exist in the atmosphere. In the latter, oxygen is present to the amount of only 21 per cent. by volume, while the air absorbed by water contains 30 to 32 per cent. of the same gas. In like manner, the mean quantity of carbonic acid in the air does not exceed $\frac{5}{10000}$th parts (0·05 per cent.) of its bulk, while that expelled from water, which has been long exposed to the air, varies from 11 to 60 ten thousand parts (0·11 to 0·6* per cent.)

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* The Spaniards call it Triste de Corazon, Sorrow of the Heart.—*Burnet's Wanderings*, p. 72.

† In some species of animals, life is in like manner suspended by the absence of water. The inhabitants of some land and even marine shells may be dried and preserved for a long time in a state of torpor, and afterwards revived by immersion in water. The *Cerithium Armatum* has been brought from the Mauritius in a dry state, while snails are said to have been revived after being dried for 15 years. The *vibrio tritici* (a species of worm), was restored by Mr. Bauer, after an apparent death of nearly six years, by merely soaking it in water. The *Furcularia Anastobea*, a small microscopic animal, may be made to undergo apparent death and resuscitation many times, by alternate drying and moistening. According to Spallanzani, animalculi have been recovered by moisture, after a torpor of 27 years. These facts tend to lessen our surprise at the alleged longevity of the seeds of plants.

Thus when water falls in rain or trickles along the surface of the land, it absorbs these gaseous substances, carries them with it wherever it goes, conveys them to the roots, and into the circulation of plants, and thus, as we shall hereafter see, makes them all minister to the growth and nourishment of living vegetables.

Again, water possesses the power of dissolving many solid substances. If sugar or salt be mixed with water in certain quantities, they speedily disappear. In like manner, many other bodies, both simple and compound, are taken up by this liquid in greater or less quantity, and can only be recovered by driving off the water, through the aid of heat.

Thus it happens that the water of our springs and rivers is never pure, but holds in solution more or less of certain solid substances. Even rain water, washing and purifying the atmosphere as it descends, brings down portions of solid matter which had previously risen into the air in the form of vapour, and as it afterwards flows along or sinks into the surface of the soil, it meets with and dissolves other solid substances, the greater portion of which it carries with it wherever it enters. In this way solid substances are conveyed to the roots of plants in a fluid form, which enables them to ascend with the sap; and the supply of these naturally solid substances is constantly renewed, by the successive passage of new portions of flowing water. We shall hereafter be able to see more clearly and to appreciate more justly this beautiful arrangement of nature, as well as to understand how indispensable it is to the continued fertility of the soil.

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* Of these gases when unmixed, water absorbs very different quantities. Thus 100 volumes of water at 60° F., absorb 3·55 of oxygen, 1·53 of hydrogen, 1·47 of nitrogen, (*Henry*,) 106 of carbonic acid, or 7800 of ammonia.

Nor is it merely earthy and saline substances which the water dissolves, as it thus percolates through the soil. It takes up also substances of organic origin, especially portions of decayed animal and vegetable matter,—such as are supposed to be capable of ministering to the growth of plants,—and brings them within reach of the roots.

This solvent power of water over solid substances is increased by an elevation of temperature. Warm water, for example, will dissolve Epsom salts or oxalic acid in much larger quantity than cold water will, and the same is true of nearly all solid substances which this fluid is capable of holding in solution. To this increased solvent power of the water they absorb, is ascribed, among other causes, the peculiar character of the vegetable productions, as well as their extraordinary luxuriance, in many tropical countries.

2°. But the *affinity* which water exhibits for many solid substances is little less important and remarkable.

When newly burned lime is thrown into a limited quantity of water the latter is absorbed, while the lime heats, cracks, swells, and finally falls to a white powder. When thus perfectly slaked, it is found to be one-third heavier than before—every three tons having absorbed one ton of water. This water is retained in a solid form, more solid than water is when in the state of ice, and it cannot be entirely separated from the lime without the application of a red heat. When you lay upon your land, therefore, four tons of slaked lime, you mix with your soil one ton of water, which the lime afterwards gradually gives up, either in whole or in part, as it combines with other substances. To this fact we shall return when we hereafter consider the various ways in which lime acts, when it is employed by the farmer for the purpose of improving his land.*

For clay also, water has a considerable affinity, though by no means equal to that which it displays for quicklime. Hence, even in well drained clay lands, the hottest summer does not entirely rob the clay of its water. It cracks, contracts, and becomes hard, yet still retains water enough to keep its wheat crops green and flourishing, when the herbage on lighter soils is drooping or burned up.

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* See the subsequent lecture, "*On the action of lime when employed as a manure.*"

A similar *affinity* for water is one source of the advantages which are known to follow from the admixture of a certain amount of vegetable matter with the soil; though, as in the case of charcoal, its porosity* is probably more influential in retaining moisture near the roots of the plants.†

3°. The degree of affinity by which the elements of water are held together, exercises a material influence on the growth and production of all vegetable substances.

If I burn a jet of hydrogen gas in the air, *water is formed* by the union of the hydrogen with the oxygen of the atmosphere, for which it manifests on many occasions an apparently powerful affinity. But if into a vessel of water I put a piece of iron or zinc and then add sulphuric acid, the *water is decomposed* and the hydrogen set free, while the metal combines with the oxygen.

So in the interior of plants and animals, water undergoes continual *de*composition and *re*composition. In its fluid state, it finds its way and exists in every vessel and in every tissue. And so slight, it would appear, in such situations, is the hold which its elements have upon each other—or so strong their tendency to combine with other substances, that they are ready to separate from each other at every impulse—yielding now oxygen to one, and now hydrogen to another, as the production of the several compounds which each organ is destined to elaborate respectively demands. Yet with the same readiness do they again re-attach themselves and cling together, when new metamorphoses require it. It is in the form of water, indeed, that nature introduces the greater portion of the oxygen and hydrogen which perform so important a part in the numerous and diversified changes which take place in the interior of plants and animals. Few things are really more wonderful in chemical physiology, than the vast variety of transmutations which are continually going on, through the agency of the elements of water.

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* *Affinity* for water causes vegetable matter to combine chemically with it, *porosity* causes it merely to drink in the water mechanically, and to retain it, *unchanged*, in its pores.

† For an exposition of the intimate relation of water to the chemical constitution of the solid parts of living vegetables, see a subsequent Lecture, "*On the nature and production of the substances of which plants chiefly consist.*"

III. In the state of vapour water ministers most materially to the life and growth of plants. It not only rises into the air at 212° Fahr. when it begins to boil, but it disappears or evaporates from open vessels at almost every temperature, with a rapidity proportioned to the previous dryness of the air, and to the velocity and temperature of the atmospheric currents which pass over it. Even ice and snow are gradually dissipated in the coldest weather, and sometimes with a degree of velocity which at first sight seems truly surprising.*

It thus happens that the atmosphere is constantly impregnated with watery vapour, which in this gaseous state accompanies the air wherever it penetrates, permeates the soil, pervades the leaves and pores of plants, and gains admission to the lungs and general vascular system of animals. We cannot appreciate the influence which, in this highly comminuted form, water exercises over the general economy of organic nature.

But it is chiefly when it assumes the form of rain and dew, and re-descends to the earth, that the benefits arising from a previous conversion of the water into vapour become distinctly appreciable. The quantity of vapour which the air is capable of holding in suspension is dependent upon its temperature. At high temperatures, in warm climates, or in warm weather, it can sustain more—at low temperatures less. Hence when a current of comparatively warm air loaded with moisture ascends to or comes in contact with a cold mountain top, it is cooled down, is rendered incapable of holding the whole of the vapour in suspension, and therefore leaves behind in the form of a mist or cloud, a portion of its watery burden. In rills subsequently, or springs, the aqueous particles which float in the midst, reappear on the plains beneath, bringing nourishment* at once, and a grateful relief to the thirsty soil.

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* Mr. Howard states that a circular patch of snow 5 inches in diameter lost in the month of January 150 grains of vapour between sunset and sunrise, and 56 grains more before the close of the day, when exposed to a smart breeze on a house-top. From an acre of snow this would be equal to 1000 gallons of water during the night only.—*Prout's Bridgewater Treatise, p.* 302; *Encyclopæd. Metropol. Art. Meteorology.*

In Von Wrangell's account of his visit to Siberia and the Polar sea, translated by Major Sabine (p. 390), it is stated that, in the intense cold, not only living bodies—but the very *snow—smokes* and fills the air with vapour.

So when two currents of air charged with moisture, but of unequal temperature, meet in the atmosphere, they mix, and the mixture has the mean temperature of the two currents. But air of this mean temperature is incapable of holding in suspension the mean quantity of watery vapour; hence, as before, a cloud is formed, and the excess of moisture falls to the earth in the form of rain. In descending to refresh the earth, this rain discharges in its progress another office. It washes the air as it passes through it, dissolving and carrying those accidental vapours which, though unwholesome to man, are yet fitted to minister to the growth of plants.

The dew, celebrated through all times and in every tongue for its sweet influence, presents the most beautiful and striking illustration of the agency of water in the economy of nature, and exhibits one of those wise and bountiful adaptations, by which the whole system of things, animate and inanimate, is fitted and bound together.

All bodies on the surface of the earth radiate, or throw out rays of heat, in straight lines—every warmer body to every colder; and the entire surface is itself continually sending rays upwards through the clear air into free space. Thus on the earth's surface all bodies strive, as it were, after an equal temperature (an equilibrium of heat), while the surface as a whole tends gradually towards a cooler state. But while the sun shines this cooling will not take place, for the earth then receives in general more heat than it gives off, and if the clear sky be shut out by a canopy of clouds, these will arrest and again throw back a portion of the heat, and prevent it from being so speedily dissipated. At night, then, when the sun is absent, the earth will cool the most; on clear nights also more than when it is cloudy, and when clouds only partially obscure the sky, those parts will become coolest which look towards the clearest portions of the heavens.

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* For the nature of this *nourishment* see the subsequent Lectures, "*On the inorganic constituents of plants.*"

Now when the surface cools, the air in contact with it must cool also; and like the warm currents on the mountain side, must forsake a portion of the watery vapour it has hitherto retained. This water, like the floating mist on the hills, descends in particles almost infinitely minute. These particles collect on every leaflet, and suspend themselves from every blade of grass, in drops of "pearly dew."

And mark here a beautiful adaptation. Different substances are endowed with the property of radiating their heat, and of thus becoming cool with different degrees of rapidity, and those substances which in the air become cool first, also attract first and most abundantly the particles of falling dew. Thus in the cool of a summer's evening the grass plot is wet, while the gravel walk is dry; and the thirsty pasture and every green leaf are drinking in the descending moisture, while the naked land and the barren highway are still unconscious of its fall.

How beautiful is the contrivance by which water is thus evaporated or distilled as it were into the atmosphere—largely perhaps from some particular spots,—then diffused equably through the wide and restless air,—and afterwards precipitated again in refreshing showers or in long-mysterious dews!* But how much more beautiful the contrivance, I might almost say the instinctive tendency, by which the dew selects the objects on which it delights to fall; descending first on every living plant, copiously ministering to the wants of each, and expending its superfluity only on the unproductive waste.

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* The beauty of this arrangement appears more striking when we consider that the whole of the watery vapour in the air, if it fell at once in the form of rain, would not amount to more than 5 inches in depth on the whole surface of the globe. In England the fall of rain varies from 22 inches (London, York, and Edinburgh) to 68 (Keswick), while in some few parts of the world (St. Domingo) it amounts to as much as 150 inches. The mean fall of rain over the whole earth is estimated at 32 or 33 inches; but if we suppose it to be only 10 or 15 inches, the water which thus falls will require to be two or three times re-distilled in the course of every year. This is exclusive of dew, which in many countries amounts to a very large quantity.—See *Prout's Bridgewater Treatise*, p. 309.

And equally kind and bountiful, yet provident, is nature in all her operations, and through all her works. Neither skill nor materials are ever wasted; and yet she ungrudgingly dispenses her favours, apparently without measure,—and has subjected dead matter to laws which compel it to minister, and yet with a most ready willingness, to the wants and comforts of every living thing.

And how unceasingly does she press this her example not only of unbounded goodness, but of universal charity—above all other men—on the attention of the tiller of the soil. Does the corn spring more freshly when scattered by a Protestant hand—are the harvests more abundant on a Catholic soil,—and does not the sun shine alike, and the dew descend, on the domains of each political party?

So science, from her daily converse with nature, fails not sooner or later to take her hue and colour from the perception of this universal love and bounty. Party and sectarian differences dwindle away and disappear from the eyes of him who is daily occupied in the contemplation of the boundless munificence of the great Impartial; he sees himself standing in one common relation to all his fellow-men, and feels himself to be most completely performing his part in life, when he is able in any way or in any measure to contribute to the general welfare of all.

It is in this sense too that science, humbly tracing the footsteps of the Deity in all his works, and from them deducing his intelligence and his universal goodness—it is in this sense, that science is of no sect, and of no party, but is equally the province, and the property, and the friend of all.

§ 7. *Of the cold produced by the evaporation of water, and its influence on vegetation.*

Beautiful, however, and beneficent as are the provisions by which, in nature, watery vapour is made to serve so many useful purposes, there are circumstances in which, and often through the neglect of man, the presence of water becomes injurious to vegetation.

The ascent of water, in the form of vapour, permits the soil to dry, and fits it for the labours of the husbandman; while its descent in dew refreshes the plant, exhausted by the heat and excitement of a long summer's day. But the same tendency to ascend in vapour, gives rise to the cold unproductive character of lands in which water is present in great excess. This character you are familiar with in what are called *cold clay* soils.

The epithet *cold*, applied to such soils, though derived probably from no theoretical views, yet expresses very truly their actual condition. The surface of the fields in localities where such lands exist, is in reality less warm, throughout the year, than that of fields of a different quality, even in their immediate neighbourhood. This is readily proved, by placing the bulb of a thermometer immediately beneath the soil in two such fields, when in the hottest day a marked difference of temperature will, in general, be perceptible. The difference is dependant upon the following principle:—

When an open pan of water is placed upon the fire, it continues to acquire heat till it reaches the temperature of 212° F. It then begins to boil, but *ceases to become hotter*. Steam, however, passes off, and the water diminishes in quantity. But while the vessel remains upon the fire the water continues to receive heat from the burning fuel as it did before it began to boil. But since, as already stated, it becomes no hotter, the heat received from the fire must be carried off by the steam.

Now this is universally true. *Whenever water is converted into steam, the ascending vapour carries off much heat along with it.*

This heat is not missed, or its loss perceived, when the vapour or steam is formed over a fire; but let water evaporate in the open air from a stone, a leaf, or a field, and it must take heat with it from these objects—and the surface of the stone, the leaf, or the field, must become colder.

That stone or leaf also must become coldest from which the largest quantity of vapour rises.

Now, let two adjoining fields be wet or moist in different degrees, that which is wettest will almost at all times give off the largest quantity of vapour, and will therefore be the coldest. Let spring arrive, and the genial sun will gently warm the earth on the surface of the one, while the water in the other will swallow up the heating rays, and cause them to re-ascend in the watery vapour. Let summer come, and while the soil of the one field rises at mid-day to perhaps 100° F. or upwards, that of the other may, in ordinary seasons, rarely reach 80° or 90°—in wet seasons may not even attain to this temperature, and only in long droughts will derive the full benefit of the solar rays. I shall hereafter more particularly advert to the important influence which a high temperature in the soil exercises over the growth of plants, the functions of their several parts, and their power of ripening seeds—as well as to certain beautiful adaptations by which nature, when left to herself, is continually imparting to the soil, especially in northern latitudes, those qualities which fit it for deriving the greatest possible benefit from the presence of the sun's rays. In the mean time you are willing to concede that warmth in the soil is favourable to the success of your agricultural pursuits. What, then, is the cause of the coldness and poverty, the fickleness and uncertainty of produce, in land of the kind now alluded to? It is the presence of too much water. What is the remedy? A removal of the excess of water. And how? By effectual drainage.

There are other benefits to the land, which follow from this removal of the excess of water by draining, of which it would here be out of place to treat; but a knowledge of the above principle shows you that the first effect upon the soil is the same as if you were to place it in a warmer climate, and under a milder sky—where it could bring to maturity other fruits, and yield more certain crops.

The application of this merely rudimentary knowledge will enable you to remove from many improvable spots the stigma of being *poor* and *cold*; an appellation hitherto applied to them,—not because they are by nature unproductive, but because ignorance, or indolence, or indifference, has hitherto prevented their natural capabilities from being either appreciated or made available.

Note.—In reference to the supposed fertilizing effect of snow, adverted to in the above lecture, I may mention a fact observed by Heyer, and quoted by Liebig (p. 125), that willow branches immersed in snow water put forth roots three or four times longer than when put into pure distilled water, and that the latter remained clear while the snow water became coloured. This shows that snow contains something not present in distilled water, which is capable of accelerating the growth of plants. The experiment would have been more instructive in regard to natural operations, had the effect of the snow water been compared with that of an equal bulk of rain water, collected under similar circumstances.

LECTURE III.

Carbonic and oxalic acids, their properties and relations to vegetable life—Carbonic oxide and light carburetted hydrogen, their properties and production in nature—Ammonia, its properties and relations to vegetable life.

§ 1. *Carbonic acid, its properties and relations to vegetable life.*

When charcoal is burned in the air it combines slowly with oxygen, and is transformed into carbonic acid gas. In oxygen gas it burns more rapidly and vividly, producing the same compound.

This gas is colourless, like oxygen, hydrogen, and nitrogen, but is readily distinguished from all these, by its acid taste and smell, by its solubility in water, by its great density, and by its reddening vegetable blues. Water at 60 F. and under the ordinary pressure of the atmosphere, dissolves rather more than its own bulk of this gas (100 dissolve 106), and, however the pressure may be increased, it still dissolves the same bulk.

All gases diminish in bulk uniformly as the pressure to which they are subjected is increased. Thus under a pressure of two atmospheres they are reduced to one-half their bulk, of three atmospheres to one-third, and so on. When water, therefore, is saturated with carbonic acid under great pressure, as in the manufacture of soda water, though it still dissolves only its own bulk, yet it retains a weight of the gas which is proportioned to the pressure applied. For the same reason also, when the pressure is removed, as in drawing the cork from a bottle of water so impregnated, the gas expands and escapes, causing a lively effervescence, and the water retains only its own bulk at the existing pressure. This solution in water has a slightly sour taste, and reddens vegetable blues. These properties it owes to the presence of the gas, which is therefore what chemists call an *acid** body, and hence its name of carbonic *acid*.

This gas is one-half heavier than atmospheric air, its density being 1·524, and hence it may be poured through the air from one vessel to another. Hence also, when it is evolved from crevices in the earth, in caves, in wells, or in the soil, this gas diffuses itself through the atmosphere and ascends into the air, much more slowly than the elementary gases described in the previous lecture. Where it issues from the earth in large quantity, as in many volcanic districts, it flows along the surface like water, enters into and fills up cracks and hollows, and sometimes reaches to a considerable distance from its source, before it is lost among the still air.

Burning bodies are extinguished in carbonic acid, and living beings, plunged into it, instantly cease to breathe. Mixed with one-ninth of its bulk of this gas the atmospheric air is rendered unfit for respiration. It is, however, the principal food of plants, being absorbed by their leaves and roots in large quantity. Hence the presence of carbonic acid in the atmosphere is necessary to the growth of plants, and they have been observed to thrive better when the quantity of this gas in the air is considerably augmented. Common air, as has been already stated, does not contain more on an average than $\frac{1}{2500}$th of its bulk of carbonic acid, but De Saussure found that plants *in the sunshine* grew better when it was increased to $\frac{1}{12}$th of the bulk of the air, but beyond this quantity they were injured by its presence, even when exposed to the sun. When the carbonic acid amounted to one-half, the plants died in seven days; when it reached two-thirds of the bulk of the air, they ceased to grow altogether. In the shade any increase of carbonic acid beyond that which naturally exists in the atmosphere of our globe, was found to be injurious.

These circumstances it is of importance to remember. Did the sun *always shine* on every part of the earth's surface, the quantity of carbonic acid in the atmosphere might probably have been increased with advantage to vegetation. But every such increase would have rendered the air less fit for the respiration of existing races of animals. Thus we see that not only the nature of living beings, both plants and animals, but also the periodical absence of the sun's rays, have been taken into account in the present arrangement of things.

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* Acids have generally a sour taste, redden vegetable blues, or combine with *bases* such as lime, soda, potash, &c., to form *salts*.

In perpetual sunshine plants would flourish more luxuriantly in air containing more carbonic acid, but they would droop and die in the shade. This is one of those proofs of *unity of design* which occasionally force themselves upon our attention in every department of nature, and compel us to recognise the regulating superintendence of *one mind.* The same hand which mingled the ingredients of the atmosphere, also set the sun to rule the day *only*,—tempering the amount of carbonic acid to the time of his periodical presence, as well as to the nature of animal and vegetable life.

Carbonic acid consists of one equivalent of carbon and two of oxygen, and is represented by $C\,O^2$. It unites with bases (potash, soda, lime, &c.), and forms compounds known by the name of *carbonates.* Thus *pearlash* is an impure *carbonate of potash*,—the common soda of the shops, *carbonate of soda*,—and limestone or chalk, *carbonate of lime.* From these compounds it may be readily disengaged by pouring upon them diluted muriatic or sulphuric acids. From limestone it is also readily expelled by heat, as in the common lime-kilns. During this process the limestone loses nearly 44 per cent.* of its weight, a loss which represents the quantity of carbonic acid driven off.†

Common carbonate of lime, in its various forms of chalk, hard limestone, or marble, is nearly insoluble in water, but it dissolves readily in water containing carbonic acid. Thus, if a current of this gas be passed through lime-water, the liquid speedily becomes milky from the formation and precipitation of carbonate of lime, but after a short time the cloudiness disappears, and the whole of the lime is re-dissolved. The application of heat to this clear solution expels the excess of carbonic acid, and causes the carbonate of lime again to fall.

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* 43·7 when pure and dry.

† Hence by burning limestone on the spot where it is quarried, nearly one-half of the cost of transport is saved.

By exposure to the air, we have already seen that water always absorbs a quantity of carbonic acid from the atmosphere. As it afterwards trickles through the rocks or through soil containing lime, it gradually dissolves a portion of this earth, equivalent to the quantity of gas it holds in solution, and thus reaches the surface impregnated with calcareous matter. Or it carries it in its progress below the surface to the roots of plants, where its earthy contents are made available, either directly or indirectly, to the promotion of vegetable growth. To the lime thus held in solution, spring and other waters generally owe their *hardness*, and it is the expulsion of the carbonic acid, by heat, that causes the deposition of the sediment so often observed when such waters are boiled.

I propose hereafter to devote an entire lecture to the consideration of the action of lime upon land, as it is employed for agricultural purposes, but I may here remark, that this solvent action of the carbonic acid in rain water is one of the principal agents in removing the lime from your soils, and in rendering a fresh application necessary after a certain lapse of time. It is the cause also of that deposit of calcareous matter at the mouths of drains, which you not unfrequently see in localities where lime is laid abundantly upon the land. The greater the quantity of rain, therefore, which falls in a district, the less permanent will be the effects of liming the land—the sooner will it be robbed of this important element of a fertile soil. Still carbonic acid is only one of several agents which act almost unceasingly in thus removing the lime from the land, a fact I shall hereafter have occasion more fully to explain.

In nature, carbonic acid is produced under a great variety of circumstances. It is given off from the lungs of all animals during respiration. It is formed during the progress of fermentation. Fermented liquors owe their sparkling qualities to the presence of this gas. During the decay of animal and vegetable substances in the air, in compost heaps, or in the soil, it is evolved in great abundance. In certain volcanic countries it issues in large quantity from springs and from cracks and fissures in the surface of the earth; while the vast amount of carbon contained in the wood and coal daily consumed by burning, is carried up into the atmosphere, chiefly in the form of carbonic acid. We shall hereafter consider the relation which exists between these several sources of supply and the proportion of carbonic acid permanently present in the air and so necessary to the support of vegetable life.

§ 2. *Oxalic acid, its properties and relations to vegetable life.*

Oxalic acid is another compound of carbon and oxygen, which, though not known to minister either to their growth or nourishment, is yet found largely in the interior of many varieties of plants. In an uncombined state it exists in the hairs of the chick pea. In combination with potash it is found in the wood sorrel (oxalis acetosella), in the common sorrel, and other varieties of *rumex*,—in which it is the cause of the acidity of the leaves and stems,—in the roots of these plants also, in the leaves and roots of rhubarb, and in the roots of tormentilla, bistort, gentian, saponaria, and many others. It is this combination with potash, formerly extracted from wood sorrel, which is known in commerce by the name of *salt of sorrel*. In combination with lime it forms the principal solid parts of many lichens, especially of the *parmeliæ* and *variolariæ*,* some of which contain as much oxalate of lime as is equivalent to 15 or 20 parts of pure acid in 100 of the dried plant.

The crystallized oxalic acid of the shops forms transparent colourless crystals, of an intensely sour taste. These crystals dissolve readily in twice their weight of cold water, and the solution, when sufficiently dilute, is agreeably acid to the taste. This acid is exceedingly poisonous. Half an ounce of the crystals is sufficient to destroy life in a very short time, and a quarter of an ounce after the lapse of a few days. It consists solely of carbon and oxygen in the proportion of two equivalents of the former to three of the latter. Its symbol is $C^2 O^3$. It combines with bases, and forms salts which are known by the name of *oxalates*, and it is characterised by the readiness with which it combines with lime to form *oxalate of lime*. If a solution of the acid be poured into lime water, the mixture immediately becomes milky from the formation of this compound, which is insoluble in water.* It is this *oxalate of lime* which exists in the lichens, while *oxalate of potash* exists in the sorrels.

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* The *parmelia cruciata* and *variolaria communis* are mentioned as peculiarly rich in this acid, which used to be extracted from them for sale. A species of parmelia, collected after the droughts on the sands of Persia and Georgia, contains 66 per cent. of oxalate of lime, with about 23 per cent. of a gelatinous substance similar to that obtained from Iceland moss. This lichen is used for food by the Kirghuis. A similar lichen is collected about Bagdad for a similar purpose.

Oxalic acid is one of those compounds of organic origin which we cannot form, as we can form carbonic acid by the direct union of its elements. In all our processes for preparing it artificially, we are obliged to have recourse to a substance previously *organized* in the living plant. It may be prepared from sugar, starch, or even from wood, by various chemical processes. The usual method is to digest potatoe starch with five times its weight of strong nitric acid (aquafortis), diluted with ten of water, till red fumes cease to be given off, and then to evaporate the solution. The oxalic acid separates in crystals, or, as it is usually expressed, *crystallizes* in the solution thus concentrated by evaporation.

It is not known to exist in the soil or in the waters which reach the roots of plants. Where it is found in living vegetables, therefore, it must, like the other substances they contain, have been formed or elaborated in the interior of the plant itself. By what very simple changes the production of this acid is or may be effected, we shall see in a subsequent lecture.

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* Substances that are insoluble are generally without action on the animal economy, and may be introduced into the stomach without producing any injurious effect. Hence this oxalate of lime, though it contains oxalic acid, is not poisonous. Hence also, if oxalic acid be present in the stomach, its poisonous action may be taken away by causing lime water or milk of lime to be swallowed in sufficient quantity. The acid combines with the lime, as in the experiment described in the text, and forms insoluble oxalate of lime. The common magnesia of the shops will serve the same purpose, forming an insoluble *oxalate of magnesia*. It is by performing experiments under circumstances where the results are visible—as in glass vessels—that we are enabled to predict the results in circumstances where the phenomena are not visible, and to act with as much confidence as if we could really see them.

§ 3. *Carbonic oxide, its constitution and properties.*

When carbonic acid (CO^2) is made to pass through a tube containing red-hot charcoal, it undergoes a remarkable change. Its gaseous form remains unaltered, but it combines with a second equivalent of carbon (becoming C^2O^2), which it carries off in the aeriform state. The new gas thus produced is known by the name of carbonic oxide. It consists of one equivalent of carbon united to one of oxygen, and is represented by C^2O^2, or simply CO.

This gas is colourless, without taste or smell, lighter than common air, nearly insoluble in water, extinguishes flame, does not support life; burns in the air or in oxygen gas with a blue flame, and during this combustion is converted into carbonic acid. It is produced along with carbonic acid during the imperfect combustion of coals in our fires and furnaces, but is not known to occur in nature, or to minister directly to the growth of plants.

There exists a general relation among the three compounds of carbon and oxygen above described, to which it may be interesting to advert, in connection with the subject of vegetable physiology. This relation appears when we compare together their chemical constitution, as represented by their chemical formulæ :—

Carbonic acid consists of one of carbon and two of oxygen, or CO^2 ;

Carbonic oxide, of one of carbon and one of oxygen, or CO ;

So that if carbonic acid be present in a plant, and be there deprived of one equivalent of its oxygen, by any vital action, it will be converted into carbonic oxide.

Oxalic acid consists of two of carbon and three of oxygen, or C^2O^3.

If we add together the formulæ for

$$\begin{array}{ll} \text{Carbonic acid} & = CO^2 \text{ and} \\ \text{Carbonic oxide} & = CO, \text{ we have} \\ \hline \text{Oxalic acid} & = C^2O^3. \end{array}$$

Hence this acid may be formed in the interior of plants, either by the direct union of carbonic oxide and carbonic acid, or by depriving two of carbonic acid ($2CO^2$ or C^2O^4) of one equivalent of oxygen.

When in a subsequent lecture we have studied the structure and functions of the leaves of plants, we shall see how very easy it is to understand the process by which oxalic acid is formed and deposited in the interior of plants, and by which carbonic oxide also *may be*, and probably is, produced.

§ 4. *Light carburetted hydrogen—the gas of marshes and of coal mines.*

During the decay of vegetable matter in moist places, or under water, a light inflammable gas is not unfrequently given off, which differs in its properties from any of those hitherto described. In summer it may often be seen rising up in bubbles from the bottom of stagnant pools and from marshy places, and may readily be collected.

This gas is colourless, without taste or smell, and is little more than half the weight of common air.* A lighted taper, plunged into it, is immediately extinguished, while the gas takes fire and burns with a pale yellow flame, yielding more light, however, than pure hydrogen gas, which it otherwise resembles. Animals introduced into it, instantly cease to breathe.

It consists of one equivalent of carbon (C) united to two of hydrogen (2H or H^2), and is represented by CH^2.

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* Its specific gravity, by experiment, is 0·5576.

When burned in the air or in oxygen gas, the carbon it contains is converted into carbonic acid (CO^2), and the hydrogen into water (HO).

Like oxalic acid this gas cannot, by any known process, be produced from the direct union of the carbon and hydrogen of which it consists. It is readily obtained, however, by heating acetate* of potash in a retort, with an equivalent proportion of caustic baryta.

In nature it is largely evolved in coal mines, and is the principal combustible ingredient in those explosive atmospheres which so frequently cause disastrous accidents in our mining districts.

This gas is also given off along with carbonic acid during the fermentation of compost heaps, or of other large collections of vegetable matter. It is said also to be generally present in well manured soils,† and is supposed by many to contribute in such cases to the nourishment of plants. It is, however, very sparingly soluble in water, so that in a state of solution, it cannot enter largely into the pores of the roots, even though it be abundantly present in the soil. How far it can with propriety be regarded as a general source of food to plants, will be considered in the following lecture.

§ 5. *Ammonia, its properties and relations to vegetable life.*

Ammonia is a compound of hydrogen and nitrogen. It is possessed of many interesting properties, and is supposed to perform a very important part in the process of vegetation. It will be proper, therefore, to illustrate its nature and properties with considerable attention.

Ammonia, like the nitrogen and hydrogen of which it is composed, is a colourless gas, but, unlike its elements, is easily distinguished from all other gaseous substances by its smell and taste.

It possesses a powerful penetrating odour (familiar to you in the smell of hartshorn and of common smelling salts), has a burning acrid alkaline* taste, extinguishes a lighted taper as hydrogen and nitrogen do, but does not itself take fire like the former. It instantly suffocates animals, kills living vegetables, and gradually destroys the texture of their parts.

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* *Acetate* of potash is prepared by pouring vinegar (acetic acid) on common pearlash and evaporating the solution.

† PERSOZ, *Chimie Moleculaire*, p. 547.

It is absorbed in large quantities by porous substances, such as charcoal—which, as already stated, absorbs 95 times its own bulk of ammoniacal gas. Porous vegetable substances in a decaying state likewise absorb it. Porous soils also, burned bricks, burned clay, and even common clay and iron ochre, which are mixed together on the surface of most of our fertile lands—all these are capable of absorbing or drinking in, and retaining within their pores, this gaseous substance, when it happens to be brought into contact with them.

But the quantity absorbed by water is much greater and more surprising. If the mouth of a bottle filled with this gas be immersed in water, the latter will rush up and fill the bottle almost instantaneously ; and if a sufficient supply of ammonia be present, a given quantity of water will take up as much as 670 times its bulk of the gas.

This solution of ammonia in water is the spirit of hartshorn of the shops. When *saturated*† it is lighter‡ than pure water, has the pungent penetrating odour of the gas, and its hot, burning, alkaline taste—is capable of blistering the skin, and decomposing or destroying the texture of animal and vegetable substances.

You will remark here the effect which combination has in investing substances with new characters. The two gases hydrogen and nitrogen, themselves without taste or smell, and absorbed by water in minute quantity only, form by their union a compound body remarkable both for taste and smell, and for the rapidity with which water absorbs it.

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* The term *alkaline*, as applied to taste, will be best understood by describing it as a taste similar to that of the common soda and pearl-ash of the shops.

† That is, when gas is supplied till the water refuses to take up any more.

‡ Its specific gravity is 0·875, water being 1.

Ammonia possesses also alkaline properties,* it restores the blue colour of vegetable substances that have been reddened by an acid, and it combines with acid substances to form salts.

Among gaseous substances, therefore, there are some which, like carbonic acid, have a sour taste and redden vegetable blues; others which, like ammonia, have an alkaline taste and restore the blue colour; and a third class which, like oxygen, hydrogen, and nitrogen, are destitute of taste and do not affect vegetable colours. These last are called *neutral* or indifferent substances.

Ammonia, as above stated, combines with acids and forms salts, which at the ordinary temperature of the atmosphere are all solid substances. Hence if carbonic acid gas be mixed with ammoniacal gas, a white cloud is formed consisting of minute particles of solid *carbonate* of *ammonia*—the smelling salts of the shops. Hence also a feather dipped into vinegar or dilute muriatic acid (spirit of salt), and then introduced into ammoniacal gas, forms a similiar white cloud, and becomes covered with a white down of solid *acetate* or of *muriate* of ammonia (sal ammoniac). The same appearance is readily seen by holding the feather to the mouth of a bottle containing hartshorn (liquid ammonia), from which ammoniacal gas continually escapes, and by its lightness rises into the air, and thus comes in contact with the acid upon the feather.

The fact of the production of a solid body by the union of two gases (ammonia and carbonic or muriatic acid gases) is one of a very interesting nature to the young chemist, and presents a further illustration of the *changes* resulting from chemical combination as explained in the previous lecture.

Ammonia is little more than half the weight of common air,* hence when liberated on the earth's surface it readily rises into and mingles with the atmosphere. It consists of hydrogen and nitrogen united together in the proportion of three equivalents† of hydrogen (3H or H^3) and one of nitrogen (N), and hence it is represented by the symbol ($N + 3H$), or more shortly by NH^3. 100 parts by weight contain 82½ of nitrogen and 17½ of hydrogen.‡

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* In the previous lecture, the term *acid* was explained as applying to substances possessed of a sour taste, and capable of reddening vegetable blues or combining with *bases* (potash, soda, magnesia, &c.) to form *salts; alkalies* are such as possess an alkaline taste (see previous Note), restore the blue colour to reddened vegetable substances, or combine with *acids* to form *salts*. Of salts, nitrate of soda, saltpetre (nitrate of potash), and glauber salts (sulphate of soda), are examples.

In nature, ammonia exists in considerable quantity. It is widely, almost universally, diffused, but is not known to form large deposits on any part of the earth's surface, or to enter as a constituent into any of the great mineral masses of which the crust of the globe is composed. It exists most abundantly in a *state of combination*—in the forms, for example, of muriate (sal ammoniac), of nitrate, and of carbonate of ammonia. It frequently escapes into the atmosphere in an uncombined state, especially where animal matters are undergoing decay, but it rarely exists in this free state for any length of time. It speedily unites with the carbonic acid of the air, with one or other of the numerous acid vapours which are continually rising from the earth, or with the nitric acid which is formed at the expense of the nitrogen and oxygen of which the atmosphere consists.

The influence of ammonia on vegetation appears to be of a very powerful kind. It seems not only to promote the rapidity and luxuriance of vegetation, but to exercise a powerful control over the functions of vegetable life. In reference to the nature and extent of this action, into which we shall hereafter have occasion to inquire, there are several special properties of ammonia which it will be of importance for us previously to understand.

1°. It has a powerful affinity§ for acid substances. Hence the readiness with which it unites with acid vapours when it rises into the atmosphere. Hence also when formed or liberated in the soil, in the fold-yard, in the stable, or in compost heaps, it unites with such acid substances as may be present in the soil, &c., and forms saline compounds or *salts*. All these salts appear to be more or less influential in the processes of vegetable life.

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* More nearly three-fifths, its specific gravity being 0·59, that of air being 1.

† See second Lecture.

‡ Correctly 82·545 and 17·455 respectively.

§ By *affinity* is meant the tendency which bodies have to unite and to

2°. Yet this affinity is much less strong than that which is exhibited for the same acids by potash, soda, lime, or magnesia. Hence if any of these substances be mixed or brought into contact with a salt of ammonia, the acid of the latter is taken up by the potash or lime, while the ammonia is separated in a gaseous state. Thus when sal ammoniac in powder is mixed with twice its weight of quicklime, ammoniacal gas is liberated in large quantity. This is the method by which pure ammonia is generally prepared; and one of the *many* functions performed by lime when employed for the improvement of land, especially on soils rich in animal and vegetable matter, is that of decomposing the salts, especially the organic salts, of ammonia,—as will be more fully explained when we come to treat at length of this important part of agricultural practice.*

3°. The salts which ammonia forms with the acids are all, like ammonia itself, very soluble in water. Hence two consequences follow. First, that which rises into the air in the form of gas, and there combines with the carbonic or other acids, is readily dissolved, washed out and brought to the earth again by the rains and dews; so that at the same time the air is purified for the use of animals, and the ammonia brought down for the use of plants. And second, whatever salts of ammonia are contained in the soil, being dissolved by the rain, are in a condition to be taken up,

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remain united or combined. Thus ammonia forms a solid substance with the vapour of vinegar the moment the two substances come into contact; they have, therefore, a strong tendency to unite, or an *affinity* for each other.

* See Lecture "*On the use of lime.*" Owing to this property the action of lime upon compost heaps is often injurious, by causing the evolution of the ammonia produced during the decomposition of the animal matters they contain. This escape of ammonia, even when imperceptible by the sense of smell, is easily detected by holding over the heap a feather dipped in vinegar or in spirit of salt (muriatic acid), when white fumes are immediately perceived if ammonia be present.

when wholesome, by the roots of plants; or to be carried off by the drains when injurious to vegetation.

4°. I have already alluded to the fact of this gas being absorbed by porous substances, and to its presence, in consequence, in porous soils, and in burned bricks and clay. With the purer kinds of unburned clay, however, and with the oxide of iron contained in red (or ferruginous)* soils, ammonia is supposed to form a chemical compound of a weak nature. In consequence of its affinity or feeble tendency to combine with these substances, they attract it from the air, and from decaying animal or vegetable matters, and retain it more strongly than many porous substances can,—yet with a sufficiently feeble hold to yield it up, readily as is supposed, to the roots of plants, when their extremites are pushed forth in search of food. In this case the carbonic, acetic and other acids given off, or supposed to be given off by the roots, exercise an influence to which more particular allusion will be made hereafter.

6°. In the state of carbonate it decomposes gypsum, forming carbonate of lime (chalk) and sulphate of ammonia.† The action of gypsum on grass lands, so undoubtedly beneficial in many parts of the world, has been ascribed to this *single* property; it being supposed that the sulphate of ammonia formed, is peculiarly favourable to vegetation. This question will come properly under review hereafter. I may here, however, remark that if this be the *sole* reason for the efficiency of gypsum, its application ought to be beneficial on all lands not already abounding either in gypsum or in sulphate of ammonia.‡ But if the results of experimental farming in this country are to be trusted, this is by no means the case. The action neither of this, nor probably of any other inorganic substance applied to the soil, is to be explained by a reference in *every* case to one and the *same* property only.

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* Soils reddened by the presence of oxide of iron.

† Gypsum is *sulphate* of lime—consisting of sulphuric acid (oil of vitriol) and quicklime. Carbonate of ammonia consists of carbonic acid and ammonia. When the two substances act upon each other in a moist state—the two acids change places—the sulphuric acid as it were *preferring* the ammonia, the carbonic acid the lime.

‡ Liebig says—"the striking fertility of a meadow on which gypsum is strewed depends *only* on its fixing in the soil the ammonia of the

7°. The presence or evolution of ammonia in a soil containing animal and vegetable matter in a decaying state, induces or disposes this matter to attract oxygen from the

atmosphere, which would otherwise be volatilized with the water which evaporates."*—*Organic Chemistry applied to Agriculture*, p. 86.

When we come to consider the subject of mineral manures in general, we shall study more in detail the specific action of gypsum in promoting vegetation—a very simple calculation, however, will serve to shew that the above theory of Liebig is far from affording a satisfactory explanation of all the phenomena.

Supposing the gypsum to meet with a sufficient supply of ammonia in the soil, and that it exercises its full influence, 100 lbs. of common *unburned* gypsum will fix or form sulphate with nearly 20 lbs. of ammonia containing 16½ lbs. of nitrogen. One hundred weight, therefore, (112 lbs.) will form as much sulphate as will contain 22½ lbs. of ammonia, and if introduced without loss into the interior of plants will furnish them with 18½ lbs. of nitrogen.

1°. In the first volume of British Husbandry, pp. 322, 323, the following experiment is recorded:

Mr. Smith, of Tunstal, near Sittingbourne, top-dressed one portion of a field of red clover with powdered gypsum at the rate of five bushels (or four hundred weight†) per acre, and compared the produce with another portion of the same field, to which no manure had been applied. The first crop was cut for hay, and the second ripened for seed. The following were the comparative results per acre:

	HAY CROP.	SEED.		STRAW.		
	cwt.	*qrs.*	*lbs.*	*cwt.*	*qrs.*	*lbs.*
Gypsumed	60	3	21	22	3	12
Unmanured	20	0	20	5	0	0
Excess of produce .	40	3	1	17	3	12

The excess of produce in all the three crops upon the gypsumed land is very large: let us calculate how much nitrogen this excess would contain. In a previous lecture (II. p. 33) it was stated as the result of Boussingault's analyses, that dry clover seed contained 7 per cent. of

[* By *fixing* is meant the forming of *sulphate* with the ammonia. Rain water is supposed to bring down with it *carbonate of ammonia* (common smelling salts), which acts upon the *sulphate of lime* (gypsum) in such a way that *sulphate of ammonia* and *carbonate of lime* are produced. The carbonate of ammonia readily volatilizes or rises again into the air, the sulphate does not—hence the use of the word *fix*.]

[† A ton of pure gypsum, when crushed, will yield 25 bushels. It should, however, always be applied by *weight*.]

air more rapidly and abundantly. The result of this is, that organic acid compounds are formed, which combine with

nitrogen, and the same experimenter found in the hay of *red clover* 1½ per cent.* (or 70 and 15 lbs. respectively in 1000.)

The seed as it was weighed by Mr. Smith would still contain one-ninth of its weight of water,† and, consequently, only 6 1-3rd per cent. of nitrogen. Let it be taken at 6 per cent. and let the *straw* be supposed to contain only 1 per cent. of nitrogen, the quantity of this element being found to diminish in the grasses after the seed has ripened, and averaging 1 per cent. in the straw of wheat, oats, and barley, the weight of nitrogen reaped in the whole crop will then be as follows:

1. 40 cwt. of hay (4480 lbs.) at 1½ per cent. of nitrogen, contain 67 lbs.
2. 85 lbs. of seed at 6 per cent. contain . . . . 5 lbs.
3. 17 cwt. 3 qrs. 12 lbs. or 2000 lbs. of straw at 1 per cent. contain 20 lbs.

Total nitrogen in the excess of crop, 92 lbs.

But, as above shewn, the five bushels or four cwt. of gypsum could fix only 90 lbs of ammonia containing 74 lbs. of nitrogen, *leaving, therefore,* 18 *lbs. or one-fifth of the whole, to be derived from some other source.*

Now this result supposes that none of the gypsum or sulphate of ammonia was carried away by the rains, but that the whole remained in the soil, and produced its greatest possible effect on the clover—*and all in one season.*

But the effect of the gypsum does not disappear with the crop to which it is actually applied. Its beneficial action is extended to the succeeding crop of wheat, and on grass lands the amelioration is visible for a succession of years. If, then, the increased produce of a single year may contain more nitrogen than the gypsum can be supposed to yield, this substance must exercise some other influence over vegetation than is involved in its supposed action on the indefinite quantity of ammonia in the atmosphere.

2°. Again, Mr. Barnard, of Little Bordean, Hants, applied 2½ cwt. per acre on two-year old sain-foin, on a clayey soil. The increased produce of the first cutting was a ton per acre, and in October fully a ton, the undressed part yielding scarcely any hay at all, while the dressed part gave 1½ tons. The second year no gypsum was applied, and the difference is said to have been at least as great.

Supposing the increased produce in all to have been 4 tons of hay, and the nitrogen it contained to have been only one per cent.—the 4 tons (8960 lbs.) would contain about 90 lbs. of nitrogen. But 2½ cwt. would fix only 46 lbs. of nitrogen in the form of ammonia; and therefore, supposing it to have produced its maximum effect, *there remain* 44 *lbs. or nearly one half of the whole, unaccounted for by the theory.*

I would not be understood to place absolute reliance on the results of the above experiments; but the way in which such results may be easily

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[* Ann. de Chim. et de Phys. lxiii. p. 225.]

[† See Lecture II. p. 33.]

the ammonia, and form ammoniacal salts.* On the decomposition of these salts by lime or otherwise—the organic acids which are separated from them, are always more advanced towards that state in which they again become fit to act as food for plants.

8°. But the most interesting, and perhaps the most important property of ammonia, is one which I have already had occasion to bring under your notice, as possessed by water also, and as peculiarly fitting that fluid for the varied functions it performs in reference to vegetable life. This property is the ease with which it undergoes decomposition, either in the air, in the soil, or in the interior of plants.

In the air it is diffused through, and intimately mixed with, a large excess of oxygen gas. In the soil, especially near the surface, it is also continually in contact with oxygen. By the influence of electricity in the air, and of lime and other bases in the soil, it undergoes a constant though gradual decomposition (oxidation), its hydrogen being chiefly converted into water, and a portion of its nitrogen into nitric acid.†

In the interior of plants this and other numerous and varied decompositions in all probability take place.

applied for the purpose of testing theoretical views, will, I hope, convince the intelligent practical agriculturist how important it is, that the results of some of the experiments he is every year making should be accurately determined by *weight and measure*. By this means data would gradually be accumulated, on which we might hope to found more unexceptionable explanations of the phenomena of vegetation, than the results obtained in our laboratories have hitherto enabled us to advance.

In a subsequent note it will be shewn that the mode in which the nitrates of soda and potash act—in other words, the theory of their action upon vegetation—may be tested by a similar simple calculation, and the importance of precise experiments made on the farm will then still further appear. It is in the hope of inducing some of my readers to make comparative trials and publish *accurate* results, that I have introduced into the Appendix (No. I.) an outline of the mode in which such experiments may most usefully be performed.

* Organic *acids* generally contain more oxygen in proportion to their carbon and hydrogen, than those which are *alkaline* or *neutral*.

† It will be remembered that ammonia is represented by NH^3, water by HO, and nitric acid by NO^5. It is easy to see, therefore, how, by means of oxygen, ammonia should be converted into water and nitric acid.

The important influence which ammonia appears to exercise over the growth of plants—the evidence for which I shall presently lay before you—is only to be explained on the supposition that numerous transformations of organic substances are effected in the interior of living vegetables—which transformations all imply the separation from each other, or the *re*-arrangement of the elements of which ammonia consists. In the interior of the plant we have seen that water, ever present in great abundance, is also ever ready to yield its hydrogen or its oxygen as occasion may require, while these same elements are never unwilling to unite again for the formation of water. So it is, to a certain degree, with ammonia. The hydrogen it contains in so large a quantity is ready to separate itself from the nitrogen in the interior of the plant, and, in concert with the other organic elements introduced by the roots or the leaves, to aid in producing the different solid bodies of which the several parts of plants are made up. The nitrogen also becomes fixed in the coloured petals of the flowers, in the seeds, and in other parts, of which it appears to constitute a necessary ingredient—passes off in the form of new compounds, in the insensible perspiration or odoriferous exhalations of the plant,—or returning with the downward circulation, is thrown off by the root into the soil from which it was originally derived. Much obscurity still rests on the actual transformations which take place in the interior of plants, yet we shall be able in a future lecture, I hope, to arrive at a tolerably clear understanding of the general nature of many of them.

Such are the more important of those properties of ammonia, to which we shall hereafter have occasion to advert. The sources, remote as well as immediate, from which plants derive this, and the other compounds we have described as contributing to the nourishment and growth of plants, will be detailed in a subsequent section.

§ 6. *Nitric acid, its constitution and properties.*

When the nitre or saltpetre of commerce is introduced into a retort, covered with strong sulphuric acid (oil of vitriol*) and heated over a lamp or a charcoal fire, red fumes are given off, and a transparent, often brownish or reddish liquid, distils over, which may be collected in a bottle or other receiver of glass. This liquid is exceedingly acid and corrosive. In small quantity it stains the skin and imparts a yellow colour to animal and vegetable substances. In larger quantity it corrodes the skin, producing a painful sore, rapidly destroys animal and vegetable life, and speedily decomposes and oxidizes† all organic substances. Being obtained from nitre, this liquid is called nitric acid. It consists of nitrogen combined with oxygen, one equivalent of the former (N) being united to 5 of the latter (O^5), and is represented by NO^5.

This acid contains much oxygen, as its formula indicates, and its action on nearly all organic substances depends upon the ease with which it is decomposed, and may be made to part with a portion of this oxygen.

In nature, it never occurs in a free state; but it is found in many intertropical (hot) countries in combination with potash, soda, and lime—in the state of *nitrates*. It is an important character of these nitrates that, like the salts of ammonia, they are all very soluble in water. Those of soda, lime, and magnesia attract moisture from the air, and in a damp atmosphere gradually assume the liquid form.

Saltpetre is a compound of nitric acid with potash (nitrate of potash). It is met with in the surface soil of many districts in Upper India, and is separated by washing the soil and subsequently evaporating (or boiling down) the clear liquid thus obtained. When pure, it does not become moist on exposure to the air. It is chiefly used in the manufacture of gunpowder, but has also been recommended and frequently and successfully tried by the practical husbandman, as an influential agent in promoting vegetation.

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* Sulphuric acid is a compound of oxygen and sulphur, which is prepared by burning sulphur with certain precautions in large leaden chambers. It is also obtained directly by distilling *green vitriol* (sulphate of iron) at a high temperature in an iron still—hence its name *oil of vitriol.* It is a heavy, oily, acid, and remarkably corrosive liquid. In a concentrated state, it is exceedingly destructive both to animal and to vegetable life.

† When a substance combines with *oxygen*, either in consequence of exposure to the air or in any other circumstances, it is said to become *oxidized.*

In combination with soda, it is found in deposits of considerable thickness in the district of Arica in Northern Peru, from whence it is imported into this country, chiefly for the manufacture of nitric and sulphuric acids. More recently its lower price has caused it to be extensively employed in husbandry, especially as a top-dressing for grass lands. Like the acid itself, these nitrates of potash and soda, when present in large quantities, are injurious to vegetation. This is probably one cause of the barrenness of the district of Arica in Peru, and of other countries, where in consequence of the little rain that falls, the nitrous incrustations are accumulated upon the soil. In small quantity they appear to exercise an important and salutary influence on the rapidity of growth, and on the amount of produce of many of the cultivated grasses. This salutary influence is to be ascribed, either in whole or in part, to the constitution and nature of the nitric acid, which these salts contain. It is chiefly with a view to the explanation I shall hereafter attempt to give of the nature of this salutary action, that I have thought it necessary here to make you acquainted with this *acid* compound of nitrogen and *oxygen*, in connection with the *alkaline* compound (ammonia) of the same gas with *hydrogen*.

Having thus shortly described both the organic elements themselves, and such chemical compounds of these elements as appear to be most concerned in promoting the growth of plants, we are prepared for entering upon the consideration of several very important questions. These questions are—

1°. From what source do plants derive the organic elements of which they are composed?

2°. In what form do plants take them up—or what proof have we that the compounds above described, really enter into plants?

3°. By what organs is the food introduced into the circulation of plants. In consequence of what peculiar structure of these several parts are plants enabled to take up the compounds by which they appear to be fed; and what are the functions of these parts, by the exercise of which the food is converted and appropriated to their own sustenance and further growth ?

4°. By what chemical changes is the food *assimilated* by plants, that is—after being introduced into the circulation, through what series of chemical changes does it pass, before it is converted by the plant into portions of its own substance ?

5°. By what natural laws or adaptations is the supply of those compounds, which are the food of plants, kept up ? Animals are supported by an unfailing succession of vegetable crops,—by the operation of what invariable laws is food continually provided for plants ?

These questions we shall consider in succession.

LECTURE IV.

Source of the organic elements of plants—Source of the carbon—Form in which it enters into the circulation of plants—Source of the hydrogen—Source of the oxygen—Source of the nitrogen—Form in which nitrogen enters into the circulation of plants—Absorption of ammonia and nitric acid by plants.

The first of the series of questions stated at the close of the preceding lecture, regards the source from which plants derive the organic elements of which they are composed. They are supported, it is obvious, at the conjoined expense of the earth and the air—how much do they owe to each, and for which elements are they chiefly and immediately indebted to the soil, and for which to the atmosphere? We must first consider the source of each element separately.

§ 1. *Source of the carbon of plants.*

We have already seen reason to believe that carbon is incapable of entering directly, in its solid state, into the circulation of plants. It is generally considered, indeed, that solid substances of every kind are unfit for being taken up by the organs of plants, and that only such as are in the liquid or gaseous state, can be absorbed by the minute vessels of which the cellular substances of the roots and leaves of plants are composed. Carbon, therefore, must enter either in the gaseous or liquid form, but from what *source* must it be derived? There are but two sources from which it can be obtained,—the soil in which the plant grows—and the air by which its stem and leaves are surrounded.

In the soil much vegetable matter is often present, and the farmer adds vegetable manure in large quantities with the view of providing food for his intended crop. Are plants really fed by the vegetable matter which exists in the soil, or by the vegetable manure that is added to it?

and advanced as a *matter of opinion*—the latter is obviously incorrect. In summer, when the sun shines the brightest, and for the greatest number of hours, the evaporation from the leaves of all plants (their insensible perspiration) is the greatest*—the largest supply of water, therefore, must at this season be absorbed by the roots, and transmitted upwards to the leaves. But this water, before it enters the roots, has derived carbonic acid and other soluble substances from the air and from the soil, in as large quantity at this period, as at any other during the growth of the plant; and these substances it will carry with it in its progress through the roots and the stem.

Are the functions of the root changed at this stage of the plant's growth? Do they now absorb pure water only, carefully separating and refusing to admit,—even such substances as are held in *solution?* Or do the same materials which minister to the growth of the plant in its earlier stages, now pass upwards to the leaf and return again in the course of the circulation unchanged and unemployed, to be again rejected at the roots? Does all this take place in the height of summer, while the plant is still rapidly increasing in size? The opinion is neither supported by facts nor consistent with analogy.

But such an opinion,—however the words above quoted may mislead some,—it is not intended to be advanced by Liebig; for, in the following page he says, that "the power which roots possess of taking up nourishment does not cease so long as nutriment is present." In summer, therefore, as well as in spring or in autumn, the plant must be ever absorbing nourishment by these roots, if the soil is capable of affording it—and thus, in the general vegetation of the globe, the increase of carbon in growing plants must, at every season of the year, be partly derived from the vegetable matter of the soil in which they grow.

§ 2. *Form in which Carbon enters into the circulation of Plants.*

Supposing it to be established that the whole of the carbon contained in plants has originally been derived from the air—we have only to inquire in what state this element exists in the atmosphere, in order to satisfy ourselves as to the *form* of combination in which it is and has been received, into the circulation of plants. In considering the constitution of the atmosphere in the preceding lecture, it was stated that carbonic acid, a compound of carbon and oxygen, is always present in it—and that, though this gas is diffused through the air in comparatively small quantity only, yet it is every where to be detected,—while no other compound of carbon is to be found in it in any appreciable quantity. We must conclude, therefore, that from this gaseous carbonic acid the whole of the carbon contained in plants has been *primarily* derived. This conclusion is confirmed by the observation so frequently made, that the leaves of plants in sunshine absorb carbonic acid, and that plants die in an atmosphere from which this gas is entirely excluded.

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* Lindley's Theory of Horticulture, p. 46.

But we have seen reason to believe that, under existing circumstances, plants also extract a portion of the carbon they contain from the soil in which they grow. In what state or form of combination do the *roots* absorb carbon?

The most abundant product of the decay of vegetable matter in the soil, is the same carbonic acid which plants inhale so largely from the atmosphere by their leaves. In a soil replete with vegetable matter, therefore, the roots are surrounded by an atmosphere more or less charged with carbonic acid. Hence if they are capable of inhaling gaseous substances, this gas will enter the roots in the aeriform state—if not, it must enter in solution in the water, which the roots drink in so largely, to supply the constant waste caused by the insensible perspiration of the leaves.

During the early fermentation of artificial manures there is also developed in the soil a variable proportion of light carburetted hydrogen (Lecture III., p. 64), which is supposed by some to enter occasionally into the roots. That it does enter, however, is doubtful,—and we are safe, I think, in considering this compound not only as an uncertain source of the carbon of plants, but as one from which, in the most favourable circumstances, they can derive only a small supply.

Thus, from the earth as from the air, the most unfailing supply of food is the gaseous carbonic acid.

But as the water passes through the soil it takes up inorganic substances—potash, soda, lime, magnesia—and conveys them through the roots into the circulation of the plants. Can it refuse to take up and to perform a similar office to the soluble organic substances it meets with, as it sinks through the soil? Or do the spongioles of the roots keep a perpetual watch over the entering waters, to prevent the introduction of every soluble form of carbon but that of carbonic acid? Or, supposing such substances introduced into the interior of the plant, are none of them *digested* there and converted to the general purposes of food? A statement of two or three facts will afford a satisfactory reply to these several questions.

1°. When plants are made to grow in infusions of madder the radicle fibres are tinged of a red colour.

2°. The flower of a white hyacinth becomes red after a few hours, when the earth in which it is planted is sprinkled with the juice of the *phytolaca decandra* (Biot.)

Therefore organic substances can enter into the roots, and thence into the circulation, of the plant.

3°. The colour of the madder does not usually extend upwards to the leaves and flowers of the plant.

4°. The colour imparted to the flower of the white hyacinth disappears in the sunshine in the course of a few days.

Organic colouring matters, therefore, undergo a chemical change either in the stem, in the leaf, or in the flower—some sooner, some later—and the same is probably the case with most other organic substances which gain admission into the interior of plants.

5°. Sir Humphry Davy introduced plants of mint into weak solutions of sugar, gum, jelly, the tanning principle, &c., and found that they grew vigorously in all of them. He then watered separate spots of grass with the same several solutions, and with common water, and found all to thrive more than that to which common water was applied

—while those treated with sugar, gum, and gelatine grew luxuriantly.[*]

Therefore different organic substances—being introduced into the circulation and there changed—are converted by plants into their own substance, or *act as food, and nourish the plant.*

We may consider it, therefore, to be satisfactorily established that, while a plant sucks in by its leaves and roots much carbon in the form of carbonic acid, it derives a *variable* portion of its immediate sustenance (of its carbon) from the soluble organic substances that are within reach of its roots.

This fact is never doubted by the practical husbandman. It forms the basis of many of his daily and most important operations, while the results of these operations are further proofs of the fact.

The nature of the soluble substances which are formed during the decay of animal and vegetable substances—and which the roots of plants are supposed to take up—will be considered in a subsequent lecture.[†]

§ 3. *Source of the hydrogen of plants.*

The source of the hydrogen of plants is less doubtful, and will require less illustration, than the source of the carbon. This elementary substance is not known to exist in nature in an uncombined state, and, therefore, it must, like carbon, enter into plants in union with some other element.

1°. Water has been already shewn to consist of hydrogen in combination with oxygen. In the form of vapour, this compound pervades the atmosphere, and plays among the leaves of plants, while in the liquid state it is diffused through the soil, and is unceasingly drunk in by the roots of all living vegetables. In the interior of plants—at least during their growth—this water is continually undergoing decomposition, and it is unquestionably the chief source of the hydrogen which enters into the constitution of their several parts. In explaining the properties of water I have already dwelt upon the apparent facility with which its elements are capable either of separating from, or of *re*-uniting to, each other, in the vascular system of animals or of plants. The reason and precise results of these transformations we shall hereafter consider.

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[*] Agricultural Chemistry, Lecture VI.

[†] This part of the subject might have been discussed here without appearing out of place—but it will come in more appropriately, I think, when treating of the nature and mode of action of *vegetable manures.*

2°. In light carburetted hydrogen (CH^2), given off as already stated during the decay of vegetable matter, and said to be always present in highly manured soils, this element, hydrogen, exists to the amount of nearly one-fourth of its weight. On the extent, therefore, to which this gaseous compound gains admission into the roots of plants, will depend the supply of hydrogen which they are capable of drawing from this source. Had we satisfactory evidence of the actual absorption of this (marsh) gas by the roots or *leaves* of plants, in any quantity, we should have no difficulty in admitting that plants might, from this source, easily obtain a considerable supply both of carbon and of hydrogen. It would be also easy to explain how (that is, by what chemical changes), it is capable of being so appropriated. But the extent to which it really acts as food to living vegetables is entirely unknown.

3°. Ammonia is another compound, containing much hydrogen,* which, as I have already stated, exercises a manifest influence on the growth of plants. If this substance enter into their circulation in any sensible quantity,—if, as some maintain, it be not only universally diffused throughout nature, but is constantly affecting, and influencing at all times, the universal functions of vegetation—there can be no doubt that the hydrogen it contains must, to an equal extent, be concerned in the production of the various organic substances which are formed or elaborated by the agency of vegetable life. How far this probable interference of the hydrogen of ammonia with the functions of the vegetable organs, will tend to explain or illustrate the influence actually exerted by this compound, we shall, by and bye, more accurately inquire. In the mean time, the quantity of ammonia, which actually enters into the circulation of plants in a state of nature, is too little known, and making the largest allowance, probably too minute, to permit us to consider it as an important source of hydrogen to the general vegetation of the globe.

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* Its formula being NH^3 or one equivalent of nitrogen and three of hydrogen.

4°. The soluble organic substances, which enter into the circulation of plants through the roots, as shewn in the preceding section, do not consist of carbon and water only, but of combinations of carbon with hydrogen and oxygen in various proportions. From these substances, therefore, plants derive an uncertain and indefinite supply of hydrogen in a state already half-organized, and probably, still more easily assimilated or converted into portions of their own substance, than when this element is combined with oxygen in the form of water.

We may, therefore, conclude generally in regard to the source of the hydrogen of plants—that though there are undoubtedly several other forms of combination in which this element may enter into their circulation, in uncertain quantity—yet that all-pervading water is the main and constant source from which the hydrogen of vegetable substances is derived.

§ 4. *Source of the oxygen of plants.*

We can at once perceive, and without difficulty, the various sources of the oxygen of plants; though it is difficult in this case also to say how much they derive from each.

1°. The water which they imbibe so largely consists in great part of oxygen,* and is easily decomposed. This alone would yield an inexhaustible supply.

2°. The atmosphere contains 21 per cent. of its bulk of oxygen, and the leaves of plants in certain circumstances are known to absorb this oxygen. The air in which they live, therefore, might be another source.

3°. Carbonic acid contains 72 per cent. by weight of oxygen, and this gas is also known to be absorbed in large quantity from the atmosphere by the leaves of plants—while its solution in water is admitted readily by the roots.

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* Eight-ninths of the weight of water are oxygen.

From any one of these sources an ample supply of oxygen might readily be obtained, and it may be considered as a proof of the vast importance of this element to the maintenance of animal and vegetable life, that it is every where placed so abundantly within the reach of living beings. It is from the first of these sources, however, from the water they contain, that plants are believed to derive their principal supply. The reasons on which this opinion is founded will appear, when we shall have considered the functions of the several parts of plants, and the chemical changes to which the food is subjected in the course of the vegetable circulation.

§ 5. *Source of the nitrogen of plants.*

The quantity of nitrogen present in plants is very small, compared with that of any of the other elements which enter into their constitution. Of this you will be reminded, by a reference to the analyses of hay, oats, and potatoes, exhibited in the second lecture (page 33), which shew that the nitrogen contained in these several crops, when perfectly dried at 240° F., is respectively $1\frac{1}{2}$, $2\frac{1}{5}$, and $1\frac{1}{5}$ per cent. In the state in which they are usually given to cattle they contain a still less per centage of nitrogen, in consequence of the quantity of water still present in them. Thus raw potatoes as they are given to cattle contain only $\frac{1}{3}$ of a per cent. of nitrogen, hay $1\frac{1}{3}$ per cent., and oats $1\frac{9}{10}$* per cent. or a hundred pounds of each contain 5 ounces, 1 pound 5 ounces, and 1 pound 14 ounces respectively.

It would appear at first sight as if this small quantity of nitrogen could be of little importance to the plant, especially since, as we shall hereafter see, it does not enter as a constituent into those vegetable substances, such as woody fibre, starch, sugar, and gum, which plants produce in the greatest abundance, and of which their own stems and branches chiefly consist. The same remark, however, applies to this, as to many other cases which present themselves to the chemist, during his analyses, especially of organized substances,—that those elements which are present only in small quantity are as necessary—as essential—to the constitution of the particular substance in which they occur, as other elements are of which they contain much; and that if these small quantities are removed or absent, not only are the physical and chemical properties of the substance materially altered, but it is found also to exercise a very different influence on animal and vegetable life. This latter observation will present itself to you in a very striking light, when we come hereafter to study the nutritive properties of the several kinds of food by which animals are chiefly supported,—and shall see on what elementary body their relative nutritive properties depend, or by the amount of which their relative value appears at least to be indicated.

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* 0·33, 1·29, and 1·87 per cent—the potatoes containing also 72 per cent. of water, the hay 14, and the oats 15 per cent.

But a consideration of the absolute quantity of nitrogen contained in an entire crop will satisfy you that though small in comparative amount,[*] this element cannot be without its due share of importance in reference to vegetable life. Hay, as above stated, contains, as it is stacked, $1\frac{1}{3}$[†] per cent. of nitrogen, or a ton of hay contains 30 lbs. of this element. A good crop of hay, on land which is depastured during the winter, will amount to 2 or $2\frac{1}{2}$ tons[‡] per acre. Taking 2 tons as an average, the hay from one acre will contain 60lbs. of nitrogen, or from 100 acres 6000 lbs., equal to $2\frac{2}{3}$ tons of nitrogen.

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[*] That is, compared with the carbon and oxygen which plants contain.

[†] In different crops of hay *Boussingault* found in three several years the following proportions of nitrogen:—

	Hay, as commonly stacked.	Hay dried at 230° F.		
In 1836	1·18	1·04	of nitrogen	per cent.
" 1838	1.3	1·15	"	"
" 1839	1·5	1·3	"	"
" Aftermath	2·4	2·0	"	"

[‡] The Rev. Mr. Ogle, of Kirkley, Northumberland, informs me that some of his land near the Hall has yielded annually at this rate for 100 years, and without other manure than the droppings from the cattle which have fed upon it.

Allowing, therefore, nothing for the aftermath, and supposing the other crops to contain no more nitrogen than the hay does, the farmer of five hundred acres will annually carry into his stack-yard at least 13 tons of nitrogen in the form of hay, straw, grain, and other produce.*

Nature performs all her operations on a large scale, and the quantity of materials she employs are large in a corresponding degree. Hence, though *comparatively* small, the nitrogen in vegetable substances is *absolutely* large. You cannot suppose, when viewed in this light, that nitrogen is an element of little consequence in reference to vegetable life; or that in nature it should be so constantly and universally diffused without reference to some important end. If I may be allowed a familiar illustration of the mode in which small quantities of matter will affect the sensible properties of large masses, I would recall to your minds the effects of seasoning upon food, in imparting, when added in small quantity only, an agreeable relish to what would otherwise be insipid. But I need not dwell on this point, since I shall hereafter have occasion to draw your attention to certain facts in reference to the constitution of the atmosphere, which will satisfy you that, by the agency of *comparatively* feeble causes, gigantic effects are continually produced in nature,—and that we can scarcely fall into a graver error in reasoning of natural processes, than by overlooking the agency of forms of matter which present themselves to our senses in minute quantity only. In reference to insect life this truth has been long established. In the coral reefs you are familiar with the wonderful results of the persevering labour of minute animals in one element. When I come to explain the nature and origin of soils, I shall have occasion to show that even the element on which you labour—the earth, on the cultivation of which your thoughts and hands are daily employed—is occasionally indebted for some of its most valuable properties to a similar agency, often unseen by you, and though working for your good, unheeded and unthought of.

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* This *average* estimate gives but an inaccurate idea of the quantity actually contained in some species of crops. Thus red clover with the aid of gypsum will yield 3 tons of hay per acre. This hay contains more than twice the quantity of nitrogen (Boussingault) that common hay does, hence an acre of such hay would contain at least 180 lbs. of nitrogen. (See Lecture II., p. 33.)

Whence, then, is this nitrogen derived by plants? The *primary* source it is not difficult to see. We can arrive at it by a train of reasoning similar to that which led us to the atmosphere as the original source of the carbon of plants. Nitrogen does not constitute an *ingredient* of any of the solid rocks,* nor do we know any other source than the atmosphere from which it can be obtained in very large quantity. It exists, as we have seen, in many vegetables, and it is more largely present in animal substances, but these organized matters must themselves have drawn this element from a foreign source, and the atmosphere is the only one from which we can fairly assume it to have been originally derived.

But though the nitrogen, like the carbon of plants, may thus be traced to the atmosphere—as its original source—it does not follow that this element is either absorbed *directly* from the air, or, in an uncombined and gaseous state. Though the leaves of trees and herbs are continually surrounded by nitrogen, the constitution of plants may be unfitted for absorbing it by their leaves. The nitrogen may not only require to be in a state of combination before it can enter into the circulation, but it may also be capable of gaining admission only by the roots. These points are considered in the following section.

§ 6. *Form in which the nitrogen enters into the circulation of Plants.*

The question as to the form in which nitrogen enters into the circulation of plants is one which at the present moment engages much attention. It will be proper, therefore, to discuss it with considerable care.

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* Except coal, and coal itself is of vegetable origin. Throughout all rocks in which organic remains are found, more or less animal matter containing nitrogen is to be met with, but these remains are only accidentally present, and they must have derived their nitrogen during life, either directly or indirectly, from the atmosphere.

1°. It is considered an essential part of good tillage to break up and loosen the soil, in order that the air may have access to the dead vegetable matter, as well as to the living roots which descend to considerable depths beneath the surface. When thus admitted to the roots, it is impossible that some of the nitrogen of the atmosphere, as well as some of its oxygen, may be directly absorbed and apppropriated by the plant. To what extent this absorption of nitrogen may proceed, however, we have as yet no experimental results from which we can form any estimate. Whether it takes place at all or not, is wholly a matter of opinion.

2°. The leaves of plants, as will be more fully explained hereafter, absorb certain gaseous substances from the atmosphere, and we might, therefore, expect that some of the nitrogen of the air would, by this channel, be admitted into their circulation. This view, however, is not confirmed by any of the experiments hitherto made with the view of investigating the action and functions of the leaves.* We are not at liberty, therefore, to assume that any of the nitrogen which plants contain has in this way been derived directly from the air. It may be the case; but it is not yet proved.

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* See subsequent lecture "*On the structure and functions of the several parts of plants.*"

The experiments above referred to were made upon plants growing in close vessels, the air contained in which was measured and examined (analysed) both before the plants were introduced and after they had been some time in the vessel. In these experiments the bulk of the nitrogen present has sometimes been observed to increase, but *never to diminish*, in quantity. The conclusion seems satisfactory, that no nitrogen is abstracted directly from the atmosphere by the leaves of plants. Yet Boussingault* very justly remarks, that a diminution in the bulk of the nitrogen

[* Boussingault details a series of experiments in the course of which he made peas, trefoil, wheat, and oats, grow in the same pure siliceous sand containing no organic matter, and watered them with the same distilled water. The absolute quantity of nitrogen increased sensibly in the peas and trefoil during their growth; in the wheat and oats no change could be detected by analysis. From these results he is inclined to infer that the green leaves of the former have the power of *sensibly* absorbing nitrogen from the atmosphere, while those of the latter have not this power—at least under the circumstances in which the experiments were made. This conclusion, however, is not *certain*, as will presently be shewn.—See *Ann. de Chim. et de Phys.* lxvii. p. 1, and lxix. p. 353.]

3°. There is little doubt, however, that nitrogen enters the roots of plants in a state of solution. But the quantity they thus absorb is uncertain—it is supposed to be small, and must be variable.

When water is exposed to the air in an open vessel it gradually absorbs oxygen and nitrogen, though, as has been stated in a previous lecture, in proportions different from those in which they exist in the atmosphere. The whole quantity of the mixed gases thus taken up amounts to about 4 per cent. of the bulk of the water (Humboldt and Gay-Lussac), and in rain water about ⅔ of the whole consist of nitrogen. One hundred cubic inches of rain water, therefore, will carry into the soil about 2⅔ inches of nitrogen gas. But in passing through the soil, the water meets with other soluble substances before it reaches the roots, especially the deep-seated roots of plants. It takes up carbonic acid, and it dissolves solid substances, and in doing so it is a property of water to give off a portion of the other gases which it had previously absorbed from the air.

But let us suppose that rain water actually takes to the roots, and carries with it into the circulation of the plant, 2 per cent. of its bulk of nitrogen, and let us calculate how much of the nitrogen it contains a crop of hay could in this way derive from the air.

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too small to be detected in the ordinary mode of making these experiments, would be sufficient to account for a considerable portion of that comparatively small quantity of nitrogen which is present in all living plants. While, therefore, we accord their due weight to these researches of the vegetable physiologists, we are not to consider them as by any means decisive of the question. With this rational and cautious conclusion, Liebig is not satisfied; he says, "We have not the slightest reason for believing that the nitrogen of the atmosphere takes part in the processes of assimilation of plants and animals; on the contrary, we know that many plants emit the nitrogen which is absorbed by their roots either in the gaseous form or in solution in water." (p. 70.) But if they occasionally expire nitrogen by their leaves, why must this nitrogen be exactly that portion which has previously been absorbed by the roots in the uncombined state, and the quantity of which is so uncertain and so indefinite?

The quantity of rain that falls at York from the first of March to the middle of June—during which time the grass grows and generally ripens—is about five inches.* On a square foot, therefore, there fall 720 cubic inches of water, containing 2 per cent. of their bulk, or 14 cubic inches, of nitrogen, weighing 4¼ grains. This gives 28 lbs. for the quantity of nitrogen thus brought to the soil over an entire acre. But if we consider how the rain falls in our climate, we cannot suppose the grass in a field to absorb by its roots, and afterwards perspire by its leaves, more than one-third of the whole. This quantity would carry with it 9 lbs. of nitrogen into the circulation of the plants—or little more than a seventh part of the 60 lbs. which, as we have seen, are taken off the field in a crop of hay.

Such a calculation as this affords at the best but a very rude approximation to the truth—it seems, however, to justify us in concluding that plants can derive from the air, and in an uncombined state, only a small portion of the nitrogen they are found to contain—and that they probably draw a larger supply from certain *compounds* of this elementary substance with hydrogen and oxygen—which are known to come within the reach of their roots and leaves.

The most important of these compounds, and those perhaps the most extensively concerned in influencing vegetation, are ammonia and nitric acid, the properties of which have been described in the preceding lecture.†

§ 7. *Absorption of Ammonia by plants.*

That ammonia enters directly into the circulation of plants is rendered probable by a variety of considerations.

1°. Thus it is found to be actually present in the juices of many plants. In that of the beet-root, and in those of the birch and maple trees, it is associated with cane sugar (Liebig.) In the leaves of the tobacco plant, and of scurvy grass, in elder flowers, and in many fungi,* it is in combination with acid substances, and may be detected by mixing their juices with quicklime.

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* The result of experiments made in 1834 by Prof. Phillips and Mr. Edward Gray. The mean annual fall of rain at York is about 22 inches. —See fifth Report of the British Association, p. 173.

† It will be recollected that ammonia consists of one equivalent of nitrogen (N) united to three of hydrogen (H^3), being represented by NH^3; and that nitric acid consists of one of nitrogen (N) and five of oxygen (O^5), its formula being NO^5.—See Lecture III., p. 39.

2°. Some plants actually perspire ammonia. Among these is the *Chenopodium Olidum* (stinking goosefoot), which is described by Sir William Hooker as "giving out a most detestable odour, compared to putrid salt fish." In the odoriferous matter given off ammonia is contained, and may be detected by putting a glass shade over the plant, and after a time introducing a feather moistened with vinegar or dilute muriatic acid.† It is also present in the odoriferous exhalations of many sweet smelling plants and flowers.‡

3°. Nearly all vegetable substances, when distilled with water, yield an appreciable quantity of ammonia. Thus the leaves of hyssop, and the flowers of the lime tree, yield distilled waters in which ammonia can be detected (Schübler), the seeds of plants thus distilled yield it in abundance (Gay Lussac), and traces of it may be found in most vegetable extracts (Liebig).

4°. Ammonia is also given off, among other products, when wood is distilled in iron retorts for the manufacture of pyroligneous acid, and by a similar treatment it may be obtained from many other vegetable substances.

The above facts, however, are not to be considered as *proofs* that ammonia enters directly into the circulation of plants either by their roots or by their leaves. That which is associated with sugar in the beet, may have been formed by the same converting power which, in the interior of the plant, has produced the sugar from carbonic acid and water. So, that exhaled by the leaves of the goosefoot, which grows in waste places, especially near the sea, may have been produced during the upward flow of the sap or during its passage over the leaf. And we *know* that the nitrogen does not exist in the state of ammonia in the seeds of plants, or in wood, or in coal—though, from all of them it may be obtained by the processes above described.

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* Schübler *Agricultur Chemie*, II., p. 56.

† Chevallier *Jour. de Pharm.* X., p. 100.

‡ Schübler, I., p. 152.

The production of ammonia, by the agency of a high temperature, may be illustrated by a very familiar experiment often performed, though for a very different purpose. The juice and dried leaf of tobacco contain nitre (nitrate of potash) and a *little* ammonia. But when tobacco is burned, ammonia in sensible quantity is given off along with the smoke, chiefly in the state of carbonate of ammonia. This may be shown by bringing a lighted cigar near to reddened litmus paper, when the blue colour will be restored; or to a red rose, when the leaves will become green; or to a rod dipped in vinegar or in dilute muriatic acid, when a white cloud will appear.*

In this case a portion of the ammonia given off by the tobacco has most probably been formed during the combustion, at the expense of the nitrogen contained in the nitrate of potash which is present in the leaf.

5°. But there are other circumstances which are strongly in favour of the opinion, that ammonia not unfrequently does enter, as such, into the circulation of plants.

Thus it is proved, by long experience, that plants grow most rapidly and most luxuriantly when supplied with manure containing substances of animal origin. These substances are usually applied to the roots or leaves in a state of fermentation or decay, during which they always evolve ammonia. Putrid urine and night-soil are rich in ammonia, and they are among the most efficacious of manures. This ammonia is *supposed* to enter into the circulation of plants along with the water absorbed by their roots, and sometimes even by the pores of their leaves. We can scarcely be said to have as yet obtained decisive proof that it does so enter, but probabilities are strongly in favour of this supposition; and when we come hereafter to consider minutely the mode in which it is likely to act, when within the plant, we shall find the probabilities derived from practical experience to be strengthened by the deductions of theory.

But though the facts so long observed in reference to the action of animal manures upon vegetation, justify us in believing that ammonia actually enters into the roots, and perhaps into the leaves, of plants—we ought not hastily to conclude that all the nitrogen which plants are capable of deriving from decaying animal matter *must* enter into their circulation in the form of ammonia. Other soluble compounds containing nitrogen are formed during the decay of animal substances—they actually exist largely in the liquid manures of the stable and fold-yard, and they can scarcely fail, when applied to the soil, to be to a certain extent absorbed by the roots of plants. This *urea* is a substance containing much nitrogen, which exists in the urine or excrements of most animals, and by its decomposition produces carbonate of ammonia. But being very soluble, this substance may enter directly into the roots, and may be there decomposed, and made to give up its nitrogen to the living plant. To other compound substances of animal origin the same observation may apply,*—so that while the fact, that animal manure in a state of fermentation is very beneficial to vegetation, may be considered as rendering it highly probable that the ammonia which such manure contains, enters directly and supplies much nitrogen to the growing plants, it must not be entirely left out of view that, in nature, a portion of the nitrogen, derived from animal substances, may be obtained immediately from other compounds in which ammonia does not exist.

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* Runge, *Einleitung in die technische Chemie*, p. 375.

To what *amount* ammonia actually enters into the circulation of plants, or how much of the nitrogen they contain it actually supplies, we have no means of ascertaining. Were it abundantly present in the soil, its great solubility would enable it to enter, with the water absorbed by the roots, in almost unlimited quantity. In a subsequent section we shall consider the conditions under which ammonia is produced in nature, the comparative abundance in which it exists on the earth's surface, and the extent of the influence it may be supposed to exercise on the general vegetation of the globe.

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* Thus it may be applied more strongly to the *hippuric acid*, which exists in the urine of the horse, and other herbivorous animals. This acid decomposes naturally into *benzoic acid* and ammonia. The sweet-scented vernal-grass (*Anthoxanthum Odoratum*) by which hay is perfumed, owes its agreeable odour to the presence of this *benzoic acid*. It may, therefore, be supposed that, where cattle and horses graze, the grasses actually absorb the *hippuric* acid contained in the urine, which reaches their roots, decompose it as it ascends with the sap, appropriate its nitrogen, and exhale the odoriferous benzoic acid.

§ 8. *Absorption of nitric acid by plants.*

1°. That ammonia is actually present in the juices of many living vegetables has been adduced, as a kind of presumptive evidence, that this compound is directly absorbed by plants. A similar presumption is offered in favour of the direct entrance of nitric acid, by its invariable presence in combination with potash, soda, lime, or magnesia, in the juices of certain common and well known plants. Thus it is said to be always contained in the juices of the tobacco plant, of the sunflower, of the goosefoot,[*] and of common borage. The nettle is also said to contain it, and it has been detected in the grain of barley.[†] It exists probably in the juices of many other plants in which it has not hitherto been sought for. Were we, therefore, entitled, from the mere presence of this acid in plants, to infer that it had really entered by their roots or leaves, we should have no hesitation in drawing our conclusion. But, like ammonia, it may have been formed in the interior of the living vegetable ;[‡] and hence the fact of its presence proves nothing in regard to the state in which the nitrogen it contains entered into the circulation of the plant.

2°. But nitric acid, like ammonia, exerts a powerful influence on the growing crop, whether of corn or of grass. Animal matters, as we have seen, give off ammonia during their decay, and manures are rich and efficacious in proportion to the quantity of animal manure they contain.

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[*] *Chenopodium*, probably in all the species of this genus.—See Liebig, p. 82.

[†] Grisenthwaite (*New Theory of Agriculture*, p. 105) says, it is always present in barley in the form of nitrate of soda.—*See Appendix.*

[‡] When the beet-root arrives at maturity, the *sugar* begins to diminish, and saltpetre or other nitrates to be *formed*, probably at the expense of the ammonia which the juice previously contained.—Decroizelles, *Jour. de Phar.*, X., p. 42.

The crop produced also is valuable and rich in nitrogen in like proportion. Therefore, as already stated, it is inferred that ammonia enters directly into the living plant, and supplies it with nitrogen.

The effect of nitric acid is similar in kind, and perhaps equal in degree. Applied to the young grass or sprouting shoots of grain, it hastens and increases their growth, it occasions a larger produce of grain, and this grain, as when ammonia is employed, is richer in *gluten*, and more nutritious in its quality.[*] An equal breadth of the same field yields a heavier produce, and that produce, weight for weight, contains more when saltpetre or nitrate of soda have been applied in certain quantities to the young plants which grow upon it. It is reasonable to conclude, therefore, that the acid of the nitrates, in some form or other, is capable of entering into the circulation of living plants—and of yielding to them, in whole or in part, the nitrogen they contain.

[*] The analogous effects of ammoniacal manures and of the nitrates on the relative quantities of *gluten* and starch in grain, are shewn by the following experiments:

Hermbstaedt sowed equal quantities of the same wheat, on equal plots of the same ground, and manured them with equal weights of different manures. Then from 100 parts of each sample of grain produced, he obtained starch and gluten in the following proportions:

	Gluten.	Starch.	Produce.
Without manure	9·2	66·7	3 fold.
With vegetable manure (rotted potatoe haulm)	9·6	65·94	5 "
With cow dung	12·0	62·3	7 "
With pigeons' dung	12·2	63·2	9 "
With horse dung	13·7	61·64	10 "
With goats' dung	32·9	42·4	12 "
With sheep dung	32·9	42·8	12 "
With dried night-soil	33·14	41·44	14 "
With dried ox-blood	34·24	41·3	14 "
With dried human urine	35·1	39·3	12 "*

The manures employed by Hermbstaedt are *supposed*, during fermentation, to evolve more ammonia in the order in which they are here placed, beginning at the top of the list; while the amount and kind of the produce obtained by the use of each, afford the chief evidence in favour of the opinion that this ammonia actually enters into and yields nitrogen to the plant.

Mr. Hyett found in flour raised on two patches of the same land in

[* Schübler. *Grundsätze der Agricultur Chemie*, II. p. 170.]

But here, again, as in the case of ammonia, we are at fault in regard to the quantity of their nitrogen which plants in a state of nature actually derive from nitric acid or the nitrates. The compounds of this acid with potash, soda, lime, and magnesia (the nitrates of these substances), are all very soluble in water. The quantity of this fluid, therefore, which enters by the roots of plants, *could* easily convey into their circulation far more of these nitrates than would be alone sufficient to supply the whole of the nitrogen they require—for the formation of all their parts and products. But so it might of ammonia or its salts, as has already been shewn. I shall hereafter lay before you certain considerations which may probably lead us to approximate conclusions in regard to the relative influence exercised by these two compounds on the general vegetation of the globe.

Conclusions.—Respecting the form in which nitrogen enters into the circulation of plants, we have, therefore, I think, fairly arrived at these deductions :

1°. That the nitrogen of the atmosphere may, to a small extent, enter directly into the living vegetable either in the form of gas or in solution in water, but that supposing ni-

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Gloucestershire, the one dressed with nitrate of soda, the other undressed, the following proportions :

	Gluten.	Starch.
In the nitrated	23·25	49·5
In the unnitrated	19·	55·5

And Dr. Daubeny, in flour from wheat top-dressed with saltpetre, found—

In the nitrated	15 per cent. of gluten.
In the unnitrated	13 " " [*]

These differences are not so striking as in the case of ammonia, but they are precisely *the same in kind*, and lead to the same general conclusion in regard to the nature of the influence of the nitrates on vegetation. Accurate and repeated experiments on the precise effects of the nitrates are still much to be desired.

[* *Three Lectures on Agriculture*, p. 76.]

trogen to be in this way appropriated* by the plant, the quantity so taken up could form only a small quantity of that which vegetables actually contain.

2°. That ammonia is *capable* of entering into plants in very large quantity, and of yielding nitrogen to them, and that in European agriculture, which employs fermenting animal manure as an important means of promoting vegetable growth, it does appear to yield to cultivated plants a considerable portion of the nitrogen they contain.

3°. That nitric acid, in like manner, is *capable* of entering into and giving up its nitrogen to plants; and that where this acid is employed as an instrument of culture, the crops obtained owe part of their nitrogen to the quantity of this compound which has been applied to the growing plants. The same inference may fairly be drawn in regard to the effect of nitric acid—when in the form of nitrates, it exists or is produced naturally in the soil.

4°. That other compound bodies, such as are contained in urine, or are produced during the decay of animal matter, may also enter into the circulation of plants, and yield nitrogen to promote their growth.

On the whole, however, there seem strong reasons for believing that plants are mainly dependent on ammonia and nitric acid for the nitrogen they contain: and that they obtain it most readily, and with least *labour*, so to speak, from these compounds,—though nature has kindly fitted them for deriving a stinted supply from other sources, when these substances are not present in sufficient abundance.

How far each of these compounds is employed by nature, as an instrument in promoting the general vegetation of the globe, will be considered in a subsequent lecture.

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* Liebig and others say that plants are *incapable* of appropriating or assimilating the nitrogen which enters into their circulation in the simple state (Liebig, p. 70). We shall consider this question hereafter.

LECTURE V.

How does the food enter into the circulation of plants—Structure of the several parts of plants—Functions of the root—Course of the sap—Cause of its ascent—Functions of the stem—of the leaves—and of the bark—Circumstances by which the exercise of these functions is modified.

Having now taken a general view of the source from which plants derive the elementary substances of which their solid parts consist, and of the states of combination in which these elements enter into the vegetable circulation,—the next step in our inquiry is—*how* are these substances admitted into the interior of living plants—and under what conditions or regulations? We are thus led to study the structure and functions of the several parts of plants, and the circumstances by which the exercise of these functions is observed to be modified.

§ 1. *General structure of plants, and of their several parts.*

Plants consist essentially of three parts—the roots, the stem, and the leaves. The former spread themselves in various directions through the soil, as the latter do through the air, and the stem is dependent for its food and increase on the rapidity with which the roots shoot out and extend, and on the number and luxuriance of the leaves.

We shall obtain a clearer idea of the relative structure of these several parts by first directing our attention to that of the stem.

The stem consists apparently of four parts—the pith, the wood, the bark, and the medullary rays. The pith and the medullary rays, however, are similarly constituted, and are only prolongations of one and the same substance. The pith forms a solid cylinder of soft and spongy matter, which ascends through the central part of the stem, and varies in thickness with the species and with the age of the trunk or branch. The wood surrounds the pith in the form of a hollow cylinder, and is itself covered by another hollow cylinder of bark. In trees or branches of considerable age the wood consists of two parts, the oldest or *heart wood*, often of a brownish colour, and the newer external wood or *alburnum*, which is generally softer and less dense than the heart wood. The bark also is easily separated into two portions, the inner bark or *liber*, and the *epidermis* or outer covering of the tree. The pith and the bark are connected together by thin vertical columns or partitions, which intersect the wood and divide it into triangular segments. A cross section of the trunk or branch of a tree exhibits these thin columns extending in the form of rays, or like the spokes of a wheel, from the centre to the circumference. Though they form in reality thin and continuous vertical plates, yet from the appearance they present in the cross section of a piece of wood, they are distinguished by the name of medullary rays.

These several parts of the stem are composed of bundles of small tubes or hollow cylindrical vessels of various sizes, and of different kinds, the structure of which it is unnecessary for us to study. They are all intended to contain liquid and gaseous substances, and to convey them in a vertical, and sometimes in a horizontal, direction. The tubes which compose the wood and bark are arranged vertically, as may readily be seen on examining a piece of wood even with the naked eye, and are intended to convey the sap upwards to the leaves and downwards to the roots. Those of which the pith and medullary plates consist are arranged horizontally, and appear to be intended to maintain a lateral intercourse between the pith and the bark—perhaps even to place the heart of the tree within the influence of the external air.

The root, though prior in its origin to the stem, may nevertheless for the purpose of illustration be considered as its downward and lateral prolongation into the earth—as the branches are its upward prolongation into the air.* When they leave the lower part of the trunk of the tree, they differ little in their internal structure from the stem itself. As they taper off, however, first the heart wood, then the pith, gradually disappear, till, towards their extremities, they consist only of a soft central woody part and its covering of soft bark. These are connected with, or are respectively prolongations of, the new wood and bark of the trunk and branches. At the extreme points of the roots the bark becomes white, soft, spongy, and full of pores and vessels. It is by these spongy extremities only, or chiefly, that liquid and gaseous substances are capable either of entering into, or of making their escape from, the interior of the root.

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* The correctness of this comparison is proved by the fact that, in many trees, the branch if planted will become a root, and the root if ex-

The branches and twigs are extensions of the trunk; and of the former, the leaves may be considered as a still further extension. The fibres of the leaf are minute ramifications of the woody matter of the twigs, are connected through them with the wood of the branches and stems, and from this wood receive the sap which they contain. The green part of the leaf may be considered as a special expansion of the bark, by which it is fitted to act upon the air, in the same way as the spongy mass into which the bark is changed at the extremity of the root, is fitted to act upon the water and other substances it meets with in the soil. For as the fibres of the leaf are connected with the wood of the stem, so the green part of the leaf is connected with its bark, and from this green part the sap first begins to descend towards the root.

posed to the air, will gradually be transformed into a branch. The banana in the forest, and the currant tree in our gardens, are familiar instances of trees spontaneously planting their branches, and causing them to perform the functions of roots. In like manner, "if the stem of a young plum or cherry-tree, or of a willow, be bent in the autumn so that one-half of the top can be laid in the earth and one-half of the root be at the same time taken carefully up—sheltered at first and afterwards gradually exposed to the cold—and if in the following year the remaining part of the top and root be treated in the same way, the branches of the top will become roots, and the ramifications of the roots will become branches, producing leaves, flowers, and fruit in due season.* The tree is thus reversed in position, and the roots and branches being thus mutually convertible cannot be materially unlike in general structure.

[* Loudon's *Encyclopædia of Agriculture.*]

§ 2. *The functions of the root.*

The position in which the roots of plants in their natural state are generally placed, has hitherto prevented their functions from being so accurately investigated as those of the leaves and of the stem. While, therefore, the main purposes they are intended to serve are universally known and understood, the precise way in which these ends are accomplished by the roots, and the powers with which they are invested, are still to a considerable degree matters of dispute.

I. It appears certain that they are possessed of the power of absorbing water in large quantity from the soil, and of transmitting it upwards to the stem. The amount of water thus absorbed depends greatly upon the nature of the soil and of the climate in which a plant grows, but much also upon the specific structure of its leaves and the extent of its foliage.

II. The analogy of the leaves and young twigs would lead us to suppose that, when in a proper state of moisture, the roots should also be capable of absorbing gaseous substances from the air which pervades the soil. Experiment, however, has not yet shewn this to be the case.

We know, however, that they are capable of absorbing gases through the medium of water. For if the roots of a plant are placed in water containing carbonic acid in the state of solution, this gas is found gradually to disappear. It is extracted from the water by the roots. And if the water in which the roots are immersed be contained in a bottle only partially filled with the liquid, while the remainder is occupied by atmospheric air, the oxygen in this air will also slowly diminish. It will be absorbed by the roots through the medium of the water.*

Again, if in the place of the atmospheric air in this bottle, carbonic acid be substituted, the plant will droop and in a few days will die. The same will take place, if instead of common air or carbonic acid, nitrogen or hydrogen gases be introduced into the bottle. The plant will not live when its roots are exposed to the sole action of any of the three.

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* It will be recollected that water absorbs about 4 per cent. of its bulk of air from the atmosphere, of which about one-third is oxygen. If the roots extract this oxygen from the water, the latter will again drink in a fresh portion from the atmospheric air which floats above it.

It is obvious, therefore, that the roots of plants absorb gaseous substances from the air which surrounds their roots, at least indirectly and through the medium of water. It appears also that from this air they have the power of *selecting* a certain portion of oxygen when this gas is present in it. Thirdly, that though they can absorb carbonic acid to a limited amount without injury to the plant, yet that a copious supply of this gas, unmixed with oxygen, is fatal to vegetable life. This deduction is confirmed by the fact that, in localities where carbonic acid ascends through fissures in the subjacent rocks and saturates the soil, the growth of grass is found to be very much retarded. And, lastly, since nitrogen is believed not to be in itself noxious to vegetable life, the death of the plant in water surrounded by this gas, is supposed to imply that the presence of oxygen is necessary about the roots of a growing and healthy plant, and that one of the special functions of the roots is constantly to absorb this oxygen.

This supposition is in accordance with the fact that, in the dark, the leaves of plants absorb oxygen from the atmosphere; for we have already seen reason to expect that, from their analogous structure, the roots and leaves in similar circumstances should perform also analogous functions. At the same time, if the roots do require the access and presence of oxygen in the soil, it would further appear that those of some plants require it more than those of others; inasmuch as some genera, like the grasses, love an open and friable soil, into which the air gains easy admission; while other genera, like the clovers, prefer a denser, stiffer surface, by which the air is more completely excluded.*

III. We have in a former lecture (IV. p. 88) concluded from facts there stated, that solid substances, which are soluble in water, accompany this liquid when it enters into the circulation of the plant. This appears to be true both of organic and inorganic substances. Potash, soda, lime, and magnesia thus find their way into the interior of plants, as well as those substances of animal and vegetable origin to which the observations made in the fourth lecture were intended more especially to apply. Even *silica*,[*] considered to be almost insoluble in water, enters by the roots, and is found in some cases in considerable quantities in the stem. Some persons have hence been led to conclude that *solid* substances, undissolved, if in a minute state of division, may be drawn into the pores of the root and may then be carried by the sap upwards to the stem.

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* Sprengel, *Chemie*, II., p. 337.

Considered as a mere question of vegetable mechanics, argued as such among physiologists, it is of little moment whether we adopt or reject this opinion. One physiologist may state that the pores by which the food enters into the roots are so minute as to baffle the powers of the best constructed microscope, and, therefore, that to no particles of solid matter can they by possibility give admission—while another may believe solid matter to be capable of a mechanical division so minute as to pass through the pores of the finest membrane. As to the mere fact itself, it matters not which is right, or which of the two we follow. The adoption of the latter opinion implies in itself merely that *foreign* substances, unnecessary, perhaps injurious to vegetable life, may be carried forward by the flowing juices until in some still part of the current, or in some narrower vessel, they are arrested and there permanently lodged in the solid substance of the plant.

By inference, however, the adoption of this opinion implies also, that the inorganic substances found in plants,—those which remain in the form of ash when the plant is burned,—are *accidental* only, not *essential* to its constitution. For since they may have been introduced in a mere state of minute mechanical division suspended in the sap, they ought to consist of such substances chiefly as the soil contains in the greatest abundance, and they ought to vary in kind and relative quantity with every variation in the soil. In a clay land the ash should consist chiefly of alumina,* in a sandy soil chiefly of silica. But if, as chemical inquiry appears to indicate, the nature of the ash is not *accidental* but *essential*, and in some degree constant, even in very different soils, this latter inference is inadmissible;—and in reasoning backwards from this fact, we find ourselves constrained to reject the opinion that substances are capable of entering into the roots of plants in a solid state—and this without reference at all to the mechanical question, as to the relative size of the pores of the spongy roots or of the particles into which solid matter may be divided.

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[*] Silica is the name given by chemists to the pure matter of flint or of rock crystal. Sand and sandstones consist almost entirely of silica.

IV. We are thus brought to the consideration of the alleged selecting power of the roots, which, if rightly attributed to them, must be considered as one of the most important functions of which they are possessed. It is a function, however, the existence of which is disputed by many eminent physiologists. But as the adoption or rejection of it will materially influence our reasonings, as well as our theoretical views, in regard to some of the most vital processes of vegetation,—it will be proper to weigh carefully the evidence on which this power is assigned to the roots of plants.

1°. The leaves, as we shall hereafter see, possess in a high degree the power of selecting from the atmosphere one or more gaseous substances, leaving the nitrogen, chiefly, unchanged in bulk. The absorption of carbonic acid and the diminution of the oxygen in the experiments above described, appear to be analogous effects, and would seem to imply in the roots the existence of a similar power.

2°. Dr. Daubeny found that pelargoniums, barley (*hordeum vulgare*), and the winged pea (*lotus tetragonolobus*), though made to grow in a soil containing much strontia,† appeared to absorb none of this earth, for none was found in the ash left by the stem and roots of the plant when burned. In like manner De Saussure observed that polygonum persicaria refused to absorb acetate of lime from the soil, though it freely took up common salt.*

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* Alumina is the pure earth of clay.

† Watered with a solution of nitrate of strontia. Strontia is an earthy substance resembling lime, which is found in certain rocks and mineral veins, but which has not hitherto been observed in the ashes of plants.

3°. Plants of different species, growing in the same soil, leave, when burned, an ash which in every case contains either different substances, or the same substances in unlike proportions. Thus if a bean and a grain of wheat be grown side by side, the stem of the plant from the latter seed will be found to contain silica, from the former none.†

4°. But the same plant grown in soils unlike in character and composition, contains always—if they are present in the soil at all—very nearly the same kind‡ of earthy matters in nearly the same proportion. Thus the stalks of corn plants, of the grasses, of the bamboo, and of many others, always contain silica, in whatever soil they grow, or at least are capable of growing with any degree of luxuriance.

With the view of testing this point, Lampadius prepared five square patches of ground, manured them with equal quantities of a mixture of horse and cow dung, sowed them with equal measures of the same wheat, and on four of these patches strewed respectively five pounds of finely powdered quartz (siliceous sand), of chalk, of alumina, and of carbonate of magnesia, and left one undressed. The produce of seed from each, in the above order, weighed 24¼, 28¾, 26¼, 21½, and 20 ounces respectively. The grain, chaff, and straw from each of the patches left nearly the same quantity of ash—the weights varying only from 3·7 to 4·08 per cent., and the roots and chaff being richest in inorganic matter. The relative proportions of silica, alumina, lime, and magnesia, were *the same in all*.* Provided, therefore, the substances which plants prefer be present in the soil, the kind of inorganic matter they take up, or of ash they leave, is not *materially* affected by the presence of other substances, even in somewhat larger quantity.

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* Lindley's *Theory of Horticulture*, p. 19.

† It is not strictly correct that the bean will absorb *no* silica, but the quantity it will take up will be only one-thirteenth of that taken up by the wheat plant—the per centage of silica in the ash of bean straw being, according to Sprengel, only 0·22, while in wheat straw it is 2·87 per cent. Pea straw contains four times as much as that of the bean, or 0·996 per cent.

‡ For more precise information on this point, see the subsequent lectures, "*On the inorganic constituents of plants.*"

These facts all point to the same conclusion, that the roots have the power of selecting from the soil in which they grow, those substances which are best fitted to promote the growth or to maintain the healthy condition of the plants they are destined to feed.

5°. It has been stated above that the roots of certain plants refuse to absorb nitrate of strontia and acetate of lime, though presented to them in a state of solution—the same is true of certain colored solutions which have been found incapable of finding their way into the circulation of plants whose roots have been immersed in them. On the other hand, it is a matter of frequent observation that the roots absorb solutions containing substances which speedily cause the death of the plant. Arsenic, opium, salts of iron, of lead, and of copper, and many other substances, are capable of being absorbed in quantities which prove injurious to the living vegetable—and on this ground chiefly many physiologists refuse to acknowledge that the roots of plants are by nature endowed with any definite and constant power of selection at all. But this argument is of equal force against the possession of such a power by animals or even by man himself; since, with our more perfect discriminating powers, aided by our reason too, we every day swallow with our food what is more or less injurious, and occasionally even fatal, to human life.†

On the whole, therefore, it appears most reasonable to conclude that the roots are so constituted as (1°) to be able generally to select from the soil, *in preference*, those substances which are most suitable to the nature of the plant—(2°) where these are not to be met with, to admit certain others in their stead*—(3°) to refuse admission also to certain substances likely to injure the plant, though unable to discriminate and reject every thing hurtful or unbeneficial which may be presented to them in a state of solution.

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* Meyen *Jahresbericht*, 1839, p. 1.

† I may here remark that it is by no means an extraordinary power which these circumstances seem to shew the roots of plants to possess. In the presence of oxygen, nitrogen, and carbonic acid, in equal quantities, water will prefer and will select the latter. From a mixture of lime and magnesia, acetic or sulphuric acid will select and separate the former. Is it unreasonable to suppose the roots of plants—the organs of a living being—to be endowed with powers of discrimination at least as great as those possessed by dead matter?

The object of nature, indeed, seems to be to guard the plant against the more common and usual dangers only—not against such as rarely present themselves in the situations in which it is destined to grow, or against substances which are unlikely even to demand admission into its roots. How useless a waste of skill, if I may so speak, would it have been to endow the roots of each plant with the power of distinguishing and rejecting opium and arsenic and the thousand other poisonous substances which the physiologist can present to them, but which in a state of nature—on its natural soil and in its natural climate—the living vegetable is never destined to encounter!

V. Another function of the roots of plants, in regard to which physiologists are divided in opinion at the present day, is what is called their *excretory power*.

1°. When barley or other grain is caused to germinate in pure chalk, acetate of lime† is uniformly found to be mixed with it after the germination is somewhat advanced (Becquerel and Mateucci.)‡ In this case the acetic acid must have been given off (excreted) by the young roots during the germination of the seed.

This fact may be considered as the foundation of the excretory theory as it is called. This theory, supported by the high authority of Decandolle, and illustrated by the apparently convincing experiments of Macaire,[*] has more recently been met by counter experiments of Braconnot,[†] and is now in a great measure rejected by many eminent vegetable physiologists. It may indeed be considered as quite certain that the application of this theory by Decandolle and others to the explanation of the benefits arising from a rotation of crops, is not confirmed, or *proved* to be correct, by any experiments on the subject that have hitherto been published.[‡]

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* This conclusion is not strictly contained in the premises above stated, but the facts from which it is drawn will be fully explained in treating of the inorganic constituents of plants. It is introduced here for the purpose of giving a complete view of what appears to be the true powers of discrimination possessed by the root.

† Acetate of lime is a combination of acetic acid or vinegar with lime derived from the chalk.

‡ *Ann. de Chim. et de Phys.* lv. p. 310.

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[*] *Ann. de Chim. et de Phys.* lii. p. 225.

[†] *Ibid*, lxxii. p. 27.

[‡] The discordant results of Macaire and Braconnot were as follow:

1°. Macaire observed that when plants of *Chondrilla Muralis* were grown in rain water they imparted to it something of the smell and taste of opium. Braconnot confirmed this, but attributed it to wounds in the roots which allowed the proper juice of the plant to escape. He says it is almost impossible to free the young roots from the soil in which they have grown, without injuring them and causing the sap to exude.

2°. *Euphorbia Peplus* (Petty Spurge) imparted to the water in which it grew a gummi-resinous substance of a very acrid taste. In the hands of Braconnot it yielded to the water scarcely any organic matter, and that only slightly bitterish.

3°. Braconnot washed the soil in which plants of *Euphorbia Breoni* and *Asclepias Incarnata* were growing in pots, and obtained a solution containing earthy and alkaline salts with only a trace of organic matter.

He also washed the soil in which the Poppy (*Papaver Somniferum*) had been grown ten years successively. The solution, besides inorganic earthy and alkaline salts, gave a considerable quantity of acetic acid (in the form of acetate of lime) and a trace of brown organic matter. He infers that these several plants do not excrete any organic matter in sufficient quantity to be injurious to themselves.

4°. Macaire observed that when separate portions of the roots of the same plant of *Mercurialis Annua* were immersed in separate vessels, the one containing pure water and the other a solution of acetate of lead,—the solution of lead was absorbed by the plant—was to be traced in every part of it, and afterwards was partially transmitted to the pure water. Braconnot observed the same results, but he found the entrance of the lead into the second vessel to be owing to the ascent of the fluid up the outer surface of the one root and down the exterior of the other, and that, by preventing the possibility of this passage, no lead could be detected among the pure water.

The conclusions of Macaire, therefore, in favour of the rotation theory of Decandolle must be considered as at present inadmissible, and we shall hereafter see reason to coincide, at least to a certain extent, in the conclusion of Braconnot, "that if these excretions (of organic matter) really take place in the natural state of the plant, they are as yet so

According to Decandolle, plants, like animals, have the power of selecting from their food, as it passes through their vascular system, such portions as are likely to nourish them, and of rejecting, by their roots, when the sap descends, such as are unfit to contribute to their support, or would be hurtful to them if not rejected from their system. He further supposes that, after a time, the soil in which a certain kind of plant grows becomes so loaded with this rejected matter, that the same plant refuses any longer to flourish in it. And, thirdly, that though injurious to the plant from which it has been derived, this rejected matter may be wholesome food to plants of a different order, and hence the advantage to be derived from a rotation of crops.

There seems no good reason to doubt that the roots of plants do at times—it may be constantly—reject organic substances from their roots. The acetic acid given off during germination, and the same acid found by Braconnot in remarkable quantity in the soil in which the poppy (*papaver somniferum*) has grown—may be regarded as sufficient evidence of the fact—but the quantity of such organic matter hitherto detected among what may be safely viewed as the real excretions of plants, seems by far too small to account for the remarkable natural results attendant upon a rotation of crops.

The consideration of these results, as well as of the ge-

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obscure and so little known as to justify the presumption that some other explanation must be given of the general system of rotation." Various illustrations have been given by different observers of this supposed excreting power of the roots. Among the most recent are those of *Nietner*, who ascribes the luxuriant rye crops obtained without manure after three years of clover, to the excretions of this plant in the soil, which, like those of the pea and bean to the wheat, he supposes to be nourishing food to the rye. He also states that the beet or the turnip after tobacco has an unpleasant taste, and is scarcely eatable, which he attributes to the excretions of the tobacco plant. Meyen ascribes the effect of the clover to the green manure supplied by its roots and stubble, and that of the tobacco to the undecomposed organic substances contained in the sap and substance of the roots and stems of this plant, of which so large a quantity is left behind in the field.* These objections of Meyen are not without their weight, but we shall hereafter see that they embody only half the truth.

[Meyen's *Jahresbericht*, 1839, p. 5.]

neral theory of such a rotation, will form a distinct topic of consideration in a subsequent part of these lectures. I shall, therefore, only mention one or two facts which seem to me capable of explanation only on the supposition that the roots of plants are endowed with the power of rejecting, and that they do constantly reject, when the sap returns from the leaf, some of the substances which they had previously taken up from the soil.

1°. De Saussure made numerous experiments on the quantity of ash per cent. left by the same plant at different periods of its growth. Among other results obtained by him, it appeared—

A. That the quantity of incombustible or inorganic matter in the different parts of the plant was different at different periods of the year. Thus the dry leaves of the horse chesnut, gathered in May, left 7·2 per cent., towards the end of July 8·4 per cent., and in the end of September 8·6 per cent. of ash; the dry leaves of the hazel in June left 6·2, and in September 7 per cent.; and those of the poplar (*populus nigra*) in May 6·6, and in September 9·3 per cent. of ash. These results are easily explained on the supposition that the roots continued to absorb and send up to the leaves during the whole summer the saline and earthy substances of which the ash consisted. But—

B. He observed also that the quantity of the inorganic substances in—or the ash left by—the *entire* plant, diminished as it approached to maturity. Thus the dry plants of the vetch, of the golden rod (*solidago vulgaris*), of the turnsol (*helianthus annuus*), and of wheat, left respectively of ash, at three different periods of their growth*—

	Before flowering. *per cent.*	In flower. *per cent.*	Seeds ripe. *per cent.*
Vetch	15	12·2	6·6
Golden rod	9·2	5·7	5·0
Turnsol	14·7	13·7	9·3
Wheat	7·9	5·4	3·3

This diminution in the proportion of ash, might arise either from an increase in the absolute quantity of vegetable matter in the plants accompanying their increase in size—or from a portion of the saline and earthy matters they contained being again rejected by the roots. But if the former be the true explanation, the *relative proportions* of the several substances of which the ash itself consisted, in the several cases, should have been the same at the several periods when the experiments were made. But this was by no means the case. Thus, to refer only to the quantity of silica contained in the ash left by each of the above plants at the several stages of their growth, the ashes of the

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* Davy's *Agricultural Chemistry*, Lecture III.

	Before flowering. *per cent.*	In flower. *per cent.*	Seeds ripe. *per cent.*
Vetch contained	1·5	1·5	1·75
Golden rod	1·5	1·5	3·5
Turnsol	1·5	1·5	3·75
Wheat	12·5	26·0	51·0

If, then, the proportion of silica in the ash increased in some cases four-fold, while the whole quantity of ash left by the plant decreased, it appears evident that some part of that which existed in the plant during the earlier periods of its growth must have been excreted or rejected by the roots, as it advanced towards maturity.

2°. This conclusion is confirmed and carried farther by another consideration. The quantity of ash left by the ripe wheat plant, in the above experiments of De Saussure, amounted to 3·3 per cent.;—of which ash, 51 per cent., or rather more than one-half, was silica. This silica, it is believed, could only have entered into the circulation of the plant in a state of solution in water, and could only be dissolved by the agency of potash or soda. But according to Sprengel, the potash, soda, and silica, are to each other in the grain and straw of wheat, in the proportions of—

	Potash.	Soda.	Silica.
Grain	0·225	0·24	0·4
Straw	0·20	0·29	2·87

Or, supposing the grain to equal one-half the weight of the straw—their relative proportions in the whole plant will be nearly as 21 potash, 27 soda, 205 silica, or the weight of the silica is upwards of four times the weights of the potash and soda taken together.

Now silica requires nearly half its weight of potash to render it soluble in water,* or three-fifths of its weight of a mixture of nearly equal parts of potash and soda. The quantity of these *alkaline* substances *found* in the plant, therefore, is by no means sufficient to have dissolved and brought into its circulation the whole of the silica it contains. One of two things, therefore, must have taken place. Either a portion of the potash and soda present in the plant in the earlier stages of its growth must have escaped from its roots at a later stage,† leaving the silica behind it—or the same quantity of alkali must have circulated through the plant several times—bringing in its burden of silica, depositing it in the vascular system of the plant, and again returning to the soil for a fresh supply. In either case the roots must have allowed it egress as well as ingress. But the fact, that the *proportion* of silica in the plant goes on increasing as it continues to grow, is in favour of the latter view—and renders it very probable that the same quantity of alkali returns again and again into the circulation, bringing with it supplies of silica and probably of other substances which the plant requires from the soil. And while this view appears to be the more probable, it also presents an interesting illustration of what may *probably* be the kind of function discharged by the potash and other inorganic substances found in the substance of plants—a question we shall hereafter have occasion to consider at some length.

The above considerations, therefore, to which I might add others of a similar kind, satisfy me that the roots of plants *do possess* the power of excreting various substances which are held in solution by the sap on its return from the stem —and which having performed their functions in the interior of the plant are no longer fitted, in their existing condition, to minister to its sustenance or growth. Nor is it likely that this excretory power is restricted solely to the emission of inorganic substances. Other soluble matters of organic origin are, no doubt, permitted to escape into the soil—though whether of such a kind as must necessarily be injurious to the plant from which they have been extruded, or to such a degree as *alone* to render a rotation of crops necessary, neither reasoning nor experiment has hitherto satisfactorily shown.

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* A soluble *glass* may be made by melting together in a crucible for six hours 10 parts of carbonate of potash, 15 of silica, and 1 of charcoal powder.

† De Saussure does not state the *exact* relative quantities of potash and soda at the several periods of the growth of wheat, though they appear to have gradually diminished. It seems, indeed, to be true of many plants, that the potash and soda they contain diminishes in quantity as their age increases. Thus the weight of potash in the juice of the ripe or sweet grape, is said to be less than in the unripe or sour grape—and the leaves of the potatoe have been found more rich in potash before than after blossoming (Liebig).

VI. The roots have the power of absorbing, and in some measure of selecting, food from the soil—can they also modify or alter it as it passes through them? A colourless sap is observed to ascend through the roots. From the very extremity up to the foot of the stem a cross section exhibits little trace of colouring matter, even when the soil contains animal and vegetable substances which are soluble, and which give dark coloured solutions.* Does such matter never enter the root? If it does, it must be speedily changed or transformed into new compounds.

We have as yet too few experiments upon this subject to enable us to decide with any degree of certainty in regard to this function of the root. It is probable, however, that as the sap passes through the plant, it is constantly, though gradually, undergoing a series of changes, from the time when it first enters the root till it again reaches it on its return from the leaf.

Can we conceive the existence of any powers in the root, or in the whole plant, of a still more refined kind? The germinating seed gives off acetic acid into the soil,—does this acetic acid dissolve lime from the soil and return with it again, as some suppose (Liebig), into the circulation of the plant?† Is acetic acid produced and excreted by the seed for this very refined purpose? We have concluded that in the wheat plant the potash and soda probably go and come several times during its growth, and the ripening of its seed. Is this a contrivance of nature to make up for the scarcity of alkaline substances in the soil—or would the same mode of operation be employed if potash and soda were present in greater abundance? Or where the alkalies are present in greater abundance, might not more work be done by them in the same time,—might not the plant be built up the faster and the larger, when there were more hands, so to speak, to do the work? Is the action of inorganic substances upon vegetation to be explained by the existence of a power resident in the roots or other parts of plants, by which such operations as this are directed or superintended? There are many mysteries connected with the nature and phenomena of vegetable life, which we have been unable as yet to induce nature to reveal to us.* But the morning light is already kindling on the tops of the mountains, and we may hope that the deepest vallies will not forever remain obscure.

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* Such as the liquid manure of the fold-yard.

† Braconnot found acetate of lime in very small quantities to be singularly hurtful to vegetation, and acetate of magnesia a little less so. He only mentions, however, some experiments upon *mercurialis annua*,* and as Saussure found that some plants actually refused to take it up at all, these acetates may not be equally injurious to all plants.

[* *Ann. de Chim. et de Phys.* lxxii. p. 36.]

§ 3. *The course of the sap.*

If the trunk of a tree be cut off above the roots, and the lower extremity be immediately plunged into a solution of madder or other colouring substance, the coloured liquid will ascend and will gradually tinge the wood. This ascent will continue till the colour can also be observed in the nerves of the leaf. If at this stage in the experiment the trunk be cut across at various heights, the wood alone will appear coloured, the bark remaining entirely untinged. But if the process be allowed still to continue when the colouring matter has reached the leaf, and after some further time the stem be cut across, the bark also will appear dyed, and the tinge will be perceptible further and further from the leaf the longer the experiment is carried on, till at length both bark and wood will be coloured to the very bottom of the stem.

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* The roots of trees will travel to comparatively great distances, and in various directions in search of water: the roots of Sainfoin (*Esparsette*) will penetrate 10 or 12 feet through the calcareous rubbly subsoil, or down the fissures of limestone rocks on which they delight to grow. Is this the result of some *perceptive* power in the plant—or is it merely by *accident* that the roots display these tendencies?

Those who are in any degree acquainted with the speculations of the German physiologists of the greatest name—in regard to the *soul* and even the *immortality* of plants—will not accuse me of going *very* far in alluding to the possible existence of some such perceptive power in plants. Von Martins gets rid of objectors by speaking of them as "*scientific men to whom the power of comprehending the transcendental has been imparted in a lower degree.*"—See Meyen's *Jahresbericht*, 1839, or *Silliman's American Journal for January*, 1841, p. 170.

Or if the root of a living plant, as in the experiment of Macaire detailed in a preceding note, be immersed in a metallic solution—such as a solution of acetate of lead,—which it is capable of absorbing without immediate injury, and different portions of the plant be examined after the lapse of different periods of time,—first the stem, afterwards the leaves, then the bark of the upper part of the stem, and lastly that of the lower part of the stem, will exhibit traces of lead.

These experiments shew that the sap which enters by the roots ascends through the vessels of the wood, diffuses itself over the surface of the leaves, and then descends by the bark to the extremities of the root.

But what becomes of the sap when it reaches the root? Is it delivered into the soil, or does it recommence the same course, and again, repeatedly perhaps, circulate through the stem, leaves, and bark? This question has been partly answered by what has been stated in the preceding section. When the sap reaches the extremity of the root, it appears to give off to the soil both solid and fluid substances of a kind and to an amount which probably differ with every species of plant. The remainder of the sap and of the substances it holds in solution must be diffused through the cellular spongy terminations of the roots, and, with the new supply of liquid imbibed from the soil, returned again to the stem with the ascending current.

But what causes the sap thus to ascend and descend? By what power is it first sucked up through the roots, and afterwards forced down again from the leaves? Several answers have been given to this question.

1°. When the end of a wide tube, either of metal or of glass, is plunged into water, the liquid will rise within the tube sensibly to the same level as that at which it stands in the vessel. But if a *capillary*[*] tube be employed instead of one with a wide bore, the liquid will rise, and will permanently remain at a considerably higher level within than without the tube. The cause of this rise has been ascribed to an attraction which the sides of the tube have for the liquid, and which is sufficiently strong to raise it and to keep it up above the proper level of the water. The force itself is generally distinguished by the name of *capillary attraction*.

Now, the wood of a tree, as we have seen, is composed of a mass of fine tubes, and through these the sap has been said to rise by *capillary attraction*. But if the top of a vine be cut off when it is juicy and full of sap, the liquid will exude from the newly formed surface, and if the air be excluded, will flow for a length of time, and may be collected in considerable quantity.[†] Such a flow of the sap is not to be accounted for by mere capillary attraction—the sides of tubes cannot draw up a fluid beyond their own extremities.

2°. To supply the defect of this hypothesis, De Saussure supposed that the fluid at first introduced by capillary attraction into the extremities of the root, was afterwards propelled upwards by the alternate contraction and expansion of the tubes of which the wood of the root and stem is composed. This alternate contraction and expansion he also supposed to be caused by a peculiar *irritating* property of the sap itself, which caused each successive part of the tube into which it found admission to contract for the purpose of expelling it. Mr. Knight also ascribed the ascent of the sap to a similar contraction of certain *other* parts of the stem. Being once raised, he supposed it to return again or descend by its own weight—but in drooping branches it is obvious that the sap must be actually driven or drawn upwards from the leaves on its return to the root. These explanations, therefore, are still unsatisfactory.

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[*] Glass tubes perforated by a very fine bore, like a human hair, are called *capillary* tubes. Such are those of which thermometers are usually made.

[†] Lindley's *Theory of Horticulture*, p. 47 (note).

3°. If one end of an open glass tube be covered with a piece of moistened bladder or other fine animal membrane, tied tightly over it, and a strong solution of sugar in water be then poured into the open end of the tube, so as to cover the membrane to the depth of several inches, and if the closed end be then introduced to the depth of an inch below the surface of a vessel of pure water, the water will after a short time pass through the bladder inwards, and the column of liquid in the tube will increase in height. This ascent will continue, till in favourable circumstances the fluid will reach the height of several feet, and will flow out or run over at the open end of the tube. At the same time the water in the vessel will become sweet, indicating that while so much liquid has passed through the membrane inwards, a quantity has also passed outwards, carrying sugar along with it.* To these opposite effects *Dutrochet*, who first drew attention to the fact, gave the names of *Endosmose*, denoting the inward progress, and *Exosmose*, the outward progress of the fluid. He supposed them to be due to the action of two opposite currents of electricity, and he likens the phenomena observed during the circulation of the sap in plants, to the appearances presented during the above experiment.

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* Instead of sugar, common salt, gum, or other soluble substances may be dissolved in the water introduced at first into the tube, and the denser this solution the larger the quantity of water which will enter by the membrane, and the greater the height to which the column will rise. It ceases in all cases to rise only when the portions of liquid within and without the membrane attain nearly to the same density.* Instead of pure water the vessel into which the extremity of the tube is plunged may also contain a weak solution of some soluble substance —such as lime or soda—in which case, while the sugar, or salt, or gum, will pass outwards, in smaller quantity, the lime or soda will pass inwards, along with the currents of water in which they are severally dissolved.

[* Contain nearly the same weight of solid matter in solution.]

Without discussing the degree of probability which exists as to the influence of electricity in producing the phenomena of endosmose and exosmose, it must be admitted that the appearances themselves bear a strong resemblance to those presented in the absorption and excretion of fluids by the roots of plants—and point very distinctly to at least a kindred cause.

Thus, if the spongy termination of the root represent the thin porous membrane in the above experiment—the sap with which the tubes of the wood are filled, the artificial solution introduced into the experimental tube—and the water in the soil, the water or aqueous solution into which the closed extremity of the tube is introduced,—we have a series of conditions precisely similar to those in the experiment. Fluids ought, consequently, to enter from the soil into the roots, and thence to ascend into the stem, as in nature they appear to do.

This ascent, we have said, will continue till the fluid in the tubes of the wood (the sap) is reduced to a density as low as that of the liquid entering the roots from the soil. But in a growing tree, clothed with foliage, this will never happen. The leaves are continually exhaling aqueous vapour, as one of their constant functions, and sometimes in very large quantity. The sap, therefore, when it reaches the leaves, is concentrated or thickened, and rendered more dense by the separation of the water, so that when it descends to the root, and again begins its upward course, it will admit of large dilution before its density can be so far diminished as to approach that of the comparatively pure water which is absorbed from the soil. And this illustration of the ascent of the sap appears the more correct from the obvious purpose it points out—(in addition to others long recognised)—as served by the evaporation which is constantly taking place from the surface of the leaf.

Still the cause of the ascent of the sap is not the more clear that we can imitate it in some measure by an artificial experiment. But it will be conceded by the strictest reasoners on physical phenomena, that to have obtained the command, or even a partial control, over a natural power, is a considerable step towards a clear conception of the nature of that power itself. If the phenomena of endosmose can hereafter be clearly and indubitably traced to the agency of electricity, we shall have advanced still another step, and shall be enabled to devise other means by which a more perfect imitation of nature may be effected, or a more complete control asserted over the phenomena of vegetable circulation.

§ 4. *Functions of the stem.*

The functions of the stem are probably as various as those of the root, though the circumstances under which they are performed necessarily involve these functions in considerable obscurity.

The pith which forms the central part of the stem consists, as I have already stated, of tubes disposed horizontally. When a coloured fluid is permitted to enter the lower part of the stem in the experiments above described, the pith remains untinctured in the centre of the coloured wood. It does not, therefore, serve for the conveyance of the sap. Nor does it seem to be vitally necessary to the health and growth of the plant, since Mr. Knight has shewn that, from the interior of many trees, it may be removed without apparent injury, and in nature, as trees advance in age, it gradually diminishes in bulk, and in some species becomes apparently obliterated.

The vessels of the wood, which surrounds the pith, perform probably both a mechanical and a chemical function. They serve to convey upwards to the leaf the various substances which enter by the roots. This is their mechanical function. But during its progress upwards, the sap appears to undergo a series of changes. When it reaches the leaves it is no longer in the state in which it ascended from the root into the stem. The difficulty of extracting the sap from the wood, at different heights, has prevented very rigorous experiments from being made on its nature and contents at the several stages of its ascent. These it is obvious must vary with the species and age of the plant, and with the season of the year at which the experiment is made. But the general result to be drawn from such observations as have hitherto been made, is, that those substances which enter directly into the root, when mingled with such as have already passed through the circulation of the plant, undergo, during their ascent, a gradual preparation for that state in which they become fit to minister to the growth of the plant. This preparation is completed in a great measure in the leaf, though further changes still go on as the sap descends through the bark. This deduction is strengthened by the fact that gaseous substances of various kinds and in varying quantities exist in the interior of the wood of the growing plant. These gaseous substances, according to Boucherie, are in some cases equal in bulk to one-twentieth part of the entire trunk of the tree in which they exist. They probably move upwards along with the sap, and are more or less completely discharged into the atmosphere through the pores of the leaves. That these gaseous substances not only differ in quantity, but in kind also, with the age and species of the tree, and with the season of the year, may, I think, be considered as almost amounting to a proof that they have not been inhaled directly by the roots, but are the result of chemical decompositions which have taken place on the stem itself, as the sap mounted upwards towards the leaves.

We have seen that the roots exercise a kind of discriminating power in admitting to the circulation of the plant the various substances which are present in the soil. The vessels of the stem exhibit an analogous power of admitting or rejecting the solutions of different substances into which they may be immersed. Thus Boucherie states that, when the trunks of several trees of the same species are cut off above the roots, and the lower extremities immediately plunged into solutions of different substances, some of these solutions will quickly ascend into and penetrate the entire substance of the tree immersed in them, while others will not be admitted at all, or with extreme slowness only, by the vessels of the stems to which they are respectively presented. On the other hand, that which is rejected by one species will be readily admitted by another. Whether this partial stoppage of, or total refusal to admit, certain substances, be a mere *contractile* effort on the part of the vessels, or be the result of a chemical change by which their exclusion is effected or resisted, does not as yet clearly appear. That it does not depend upon the lightness and porosity of the wood, as might be supposed, is shewn by the observation that the poplar is less easily penetrated in this way than the beech, and the willow than the pear tree, the maple, or the plane.

These various functions of the woody part of the stem are performed chiefly by the newer wood or *alburnum*, or, as it is often called, the sap wood of the tree. As the heart wood becomes older, the tubes of which it consists are either gradually stopped up by the deposition of solid substances which have entered by the roots, or by the formation of chemical compounds, which, like concretions in the bodies of animals, slowly increase in size till the vessels become entirely closed—or they are by degrees compressed laterally by the growth of wood around them, so as to become incapable of transmitting the ascending fluids. Perhaps the result is in most cases due in part to both these causes. This more or less perfect stoppage of the oldest vessels is one reason why the course of the sap is chiefly directed through the newer tubes.*

The functions of the bark, which forms the exterior portion of the stem, will be more advantageously described, after we shall have considered the purposes served by the leaves.

§ 5. *Functions of the leaves.*

The vessels of which the sap wood is composed extend upwards into the fibres of the leaf. Through these vessels the sap ascends, and from their extremities diffuses itself over the surface of the leaf. Here it undergoes important chemical changes, the extent, if not the exact nature, of which will appear from a short description of the functions which the leaves are known or are believed to discharge.

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* As the newest roots are prolongations of the newest wood, it may be supposed that the fact of these roots being the chief absorbents from the soil, is a sufficient reason why that which is absorbed by them should also pass up through the wood with which they are most closely connected. But that the pores of the heart wood are really incapable of transmitting fluids, is shewn by plunging the newly cut stem of a tree into a coloured solution,—the newer wood will be dyed, while more or less of the central portion will remain unchanged.

1°. When the roots of a living plant are immersed in water, it is a matter of familiar observation that the water gradually diminishes in bulk, and will at length entirely disappear, even when evaporation into the air is entirely prevented. The water which thus disappears is taken up by the roots of the plant, is carried up to the leaves, is there spread out over a large surface exposed to the sun and to the air, and in the form of vapour escapes in considerable proportion through the pores of the leaves and diffuses itself through the atmosphere.

The quantity of water which thus escapes from the surface of the leaves varies with the moisture of the soil, with the species of plant, with the temperature and moisture of the air, and with the season of the year. According to the experiments of Hales, it is also dependent on the presence of the sun, and is scarcely perceptible during the night. He found that a sun-flower, 3½ feet high, lost from its leaves during 12 hours of one day 30, and of another day 20 ounces of water, while during a warm night, without dew, it lost only three ounces, and in a dewy night underwent no diminution in weight.*

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* When the escape of vapour from the leaves is more rapid than the supply of water from the roots, the leaves droop, dry, and wither. Such is sometimes the case with growing crops in very hot weather, and it always happens when a twig or flower is plucked and separated from the stem or root. When thus separated the leaves still continue to give off watery vapour into the air, and consequently the sap ascends from the twig or stalk to supply the place of the water thus exhaled.

But as the sap ascends it must leave the vessels empty of fluid, and air must rush in to fill the empty space. This will continue till nearly all the fluid has risen from the stem into the leaf, and the vessels of the wood are full of air. But if the stem of the twig or flower be placed in water, this liquid will rise into it, air will be excluded, and the freshness and bloom of the leaves and flowers will be longer preserved. If the water into which they are introduced contain any substances in solution, these will rise along with the water, and will gradually make their way through all the vessels of the wood, till they can be detected in the leaves. By this means even large trees may in a short time be saturated with saline solutions, capable of preserving them from decay. It is only necessary to cut down or saw through the tree and insert its lower extremity into the prepared solution, when the action of the sun and air upon the leaves

This loss of watery vapour by the leaf is ascribed to two different kinds of action. First, to a natural perspiration from the pores of the leaf, similar to the insensible perspiration which is continually proceeding from the skins of healthy animals; and second, to a mechanical evaporation like that which gradually takes place from the surface of moist bodies when exposed to hot or dry air. The relative amount of loss due to each of these two modes of action respectively, must differ very much in different species of plants, being dependent in a great measure on the special structure of the leaf. In all cases, however, the natural perspiration is believed very greatly to exceed the mere mechanical evaporation—though the results of Hales, and of other experimenters, shew that both processes proceed with the greatest rapidity under the influence of a warm dry atmosphere, aided by the direct rays of the sun.

Among the several purposes served by this escape of watery vapour from the surface of the leaf, it is of importance for us to notice the direct chemical influence it exercises over the growth of the plant. As the water disappears from the leaf, the roots must absorb from the soil at least an equal supply. This water brings with it the soluble substances, organic and inorganic, which the soil contains, and thus in proportion to the activity with which the leaves lose their watery vapour, will be the quantity of those substances which enter from the soil into the general circulation of the plant. This enables us to understand how substances, very sparingly soluble in water, should yet be found in the inte-

will cause it spontaneously to ascend. Thus *corrosive sublimate* (the subject of Kyan's Patent) may be injected with ease, or *pyrolignite of iron*, (iron dissolved in wood vinegar,) which Boucherie recommends as equally efficient and much more economical.* The process is finished when the liquid is found to have risen to the leaf. Coloured solutions may in the same way be injected and the wood tinged to any required shade. One of the chief benefits attendant upon the cutting of wood in the winter, appears to be that the absence of leaves prevents the exhaustion of the sap and the ascent of air into the vessels of the wood—the oxygen of this air tending to induce decay. But the sap may be retained, and the air excluded almost as effectually, at any other season of the year, by stripping the tree of its leaves and branches a few days before it is cut down.

[* *Ann. de Chim. et de Phys.* lxxiv. p. 113.]

rior of plants, and in very considerable quantity, at almost every stage of their growth.

2°. Besides watery vapour, however, the leaves of nearly all plants exhale at the same time other volatile compounds in greater or less abundance. In the petals of flowers we are familiar with such exhalations—often of an agreeable and odoriferous character. In the case of plants and trees also which emit a sensible odour, we readily recognise the fact of volatile substances being given off by the leaves. But even when the sense of smell gives us no indication of their emission from a single leaf or a single plant, the introduction of a number of such inodorous plants into the confined atmosphere of a small room after a time satisfies us that even they part with some volatile matter from their leaves, which makes itself perceptible to our imperfect organs only when in a concentrated state. The probability therefore is, that the leaves of all plants emit, along with the watery vapour which they evolve, certain other volatile substances also, though often in quantities so minute as to escape detection by our unaided senses. By the emission of these substances the plant probably relieves itself of what would prove injurious if retained, though of the chemical nature and composition of these exhalations little or nothing has as yet been ascertained.

3°. If the branch of a living plant be so bent that some of its leaves can be introduced beneath the edge of an inverted tumbler full of water, and if the leaves be then exposed to the rays of the sun, bubbles of gas will be seen to form on the leaf, and gradually to rise through the water and collect in the bottom of the tumbler. If this gas be examined it will be found to be pure oxygen.

If the water contain carbonic acid gas, or if during the experiment a little carbonic acid be introduced, this gas will be found gradually to disappear, while the oxygen will continue to accumulate.

Or if the experiment be made by introducing a living plant into a large bell glass full of common atmospheric air, allowing it to grow there for 12 hours in the sunshine, and then examining or analysing the air contained in the glass, the result will be of a precisely similar kind. The per centage of oxygen in the air will have increased.[*] And if the experiment be varied by the introduction of a small quantity of carbonic acid gas into the jar, this gas will be found as before to diminish in quantity, while the oxygen increases. The conclusion drawn from these experiments, therefore, is, that *the leaves of plants, when exposed to the rays of the sun, absorb carbonic acid from the air and give off pure oxygen gas.*

It has been already stated that the proportion of carbonic acid present in the atmosphere is exceedingly small,[†] but if for the purpose of experiment we increase this proportion in a gallon of air to five or ten per cent., introduce a living plant into it, and expose it to the sunshine, the carbonic acid will gradually disappear as before, while the oxygen will increase. And if we analyse the air and estimate the exact bulk of each of these gases present in it at the close of our experiment, we shall find that the oxygen has increased generally by as much as the carbonic acid has diminished. That is to say, if five cubic inches of the latter have disappeared, five cubic inches will have been added to the bulk of the oxygen. The above general conclusion, therefore, is rendered more precise by this experiment, which appears to shew *that under the influence of the sun's rays the leaves of plants absorb carbonic acid from the air, and at the same time give off* AN EQUAL BULK *of oxygen gas.*

And as carbonic acid (CO^2) contains its own bulk of oxygen gas[‡] combined with a certain known weight of carbon, it is further inferred that the oxygen given off by the leaves is the same which has been previously absorbed in the form of carbonic acid, and therefore it is usually stated as a function of the leaves—that *in the sunshine they absorb carbonic acid from the air,* DECOMPOSE *it in the interior of*

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[*] It will be remembered that atmospheric air contains about 21 per cent. of oxygen gas.

[†] About 1-2500th of its bulk. See Lecture II., p. 36.

[‡] This the reader will recollect is proved by burning charcoal in a bottle of oxygen gas till combustion ceases, when nearly the whole of the oxygen is converted into carbonic acid, but without change of bulk. See Lecture III., p. 57.

the leaf, retain its carbon, and again reject or emit the oxygen it contained.

This conclusion presents a very simple view of the relations of oxygen and carbonic acid respectively to the living leaf in the presence of the sun, and it appears to be fairly deduced from the facts above stated. It has occasionally been observed, however, that the bulk of oxygen given off by the leaf has not been precisely equal to that of the carbonic acid absorbed,* and hence it is also fairly concluded that a portion of the oxygen of the carbonic acid which enters the leaf is retained, and made available in the production of the various substances which are formed in the vascular system of different plants. On the other hand it is stated by Sprengel, that if compounds containing much oxygen be presented to the roots of plants, and thus introduced into the circulation, they are also decomposed, and the oxygen they contain in part or in whole given off by the leaves, so that, under certain circumstances, the bulk of the oxygen which escapes is actually greater than that of the carbonic acid which is absorbed by the leaves. Such is the case, for example, when the roots are moistened with water containing carbonic, sulphuric, or nitric acids.†

It is of importance to note these deviations from apparent simplicity in the relative bulks of the two gases which are respectively given off and absorbed by all living vegetables. There are numerous cases of the formation of substances in the interior of plants which theory would fail to account for with any degree of ease, were these apparent anomalies to be neglected. This will more distinctly appear when in a subsequent lecture we shall inquire *how* or by what chemical changes the substances which plants contain, or of which they consist, are produced from the food which they draw from the air and from the soil.

The most general and probable expression, therefore, for the function of the leaf, now under consideration, appears to be that in the sunshine the leaves absorb from the air carbonic acid, and at the same time evolve oxygen gas, the bulk of the latter gas given off being nearly equal to that of the former which is taken in—the relative bulks of the two gases varying more or less with the species of plant, as well as with the circumstances under which it is caused or is fitted to grow.*

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* See Persoz *Chimie Moleculaire*, p. 54.

† Sprengel *Chemie*, II., p. 344.

4°. Such is the relation of the leaf to the oxygen and carbonic acid of the atmosphere in the presence of the sun. During the night their action is reversed, they *emit carbonic acid and absorb oxygen.* This is proved by experiments similar to those above described. For if the plant which has remained under the bell glass for 12 hours in the sunshine—during which time the oxygen has sensibly increased, and the carbonic acid diminished in bulk—be allowed to remain in the same air through the following night, the oxygen will be found to have decreased, while the carbonic acid will be present in larger quantity than in the evening of the previous day.

The carbonic acid thus given off during the night is supposed to be partly derived from the soil through the roots, and partly from the substance of the plant itself. The oxygen absorbed either combines with the carbon of the plant to form a portion of the carbonic acid which is at the same time given off, or is employed in producing some of the other *oxidized*† compounds that exist in the sap.

As a general rule, the quantity of carbonic acid given off during the night is far from being equal to that which is absorbed during the day. Still it is obvious that a plant loses carbon precisely in proportion to the amount of this gas given off. Hence, when the days are longest, the plant will lose the least, and where the sun is brightest it will gain the fastest; since other things being equal, the decomposition of carbonic acid proceeds most rapidly where the sky is the clearest, and the rays of the sun most powerful. Hence we see why in Northern regions, where spring, summer, and autumn are all comprised in one long day—vegetation should proceed with such rapidity. The decomposition of the carbonic acid goes on without intermission, the leaves have no night of rest, but nature has kindly provided that, where the season of warmth is so fleeting, there should be no cessation to the necessary growth of food for man and beast.

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* As the oxygen given off by the leaves is always the result of a chemical decomposition, by which the carbonic acid or other compound is deprived of a portion, at least, of its oxygen or *de*-oxidized, this function of the leaves in the presence of the sun is often spoken of as their *de-oxidizing* power.

† *Oxidized*—containing oxygen in considerable quantity.

This comparison of the functions performed by the leaf, during the day and night respectively, explains the chemical nature of the *blanching* of vegetables practised by the gardener, as well as the cause of the pale colour of plants that grow naturally in the absence of light.

When exposed to the sun, the leaves of these sickly vegetables evolve oxygen, and gradually become green and healthy. Woody matter is formed, and their stems become strong and fibrous.

The light of the sun, in the existing economy of nature, is indeed equally necessary to the health of plants and of animals. The former become pale and sickly, and refuse to perform their most important chemical functions when excluded from the light. The bloom disappears from the human cheek, the body wastes away, and the spirit sinks, when the unhappy prisoner is debarred from the sight of the blessed sun. In *his* system, too, the presence of light is necessary to the performance of those *chemical* functions on which the healthy condition of the vital fluids depends.

The processes by which oxygen and carbonic acid are respectively evolved in plants have been likened by physiologists to the respiration and digestion of animals. It is supposed that when plants respire they give off carbonic acid as animals do, and that when they digest they evolve oxygen. Respiration also, it is said, proceeds at all times, digestion only in the light of the sun. Though these views are confessedly conjectural, they are founded upon striking analogies, and may reasonably be entertained as matters of opinion.

6°. Other species of decomposition also, besides that of *de-oxidization*, go on in the leaf, or are there made manifest. Thus when plants grow in a soil containing much common salt (chloride of sodium) or other chlorides, they have been observed by Sprengel and Meyen to evolve chlorine* gas from their leaves. This takes place, however, more during the night than during the day. Some plants also give off ammonia, (Lecture IV., p. 98,) while others (cruciferæ), according to Dr. Daubeny,[†] emit from their leaves pure nitrogen gas.

The evolution of chlorine implies the previous decomposition of the chlorides, which have been absorbed from the soil; while that of nitrogen may be due to the decomposition of ammonia, of nitric acid, or of some other compound containing nitrogen, which has entered into the circulation by the roots. The exact mode and nature of the decomposition of these substances, and the purposes served by them in the vegetable economy, will come under our consideration in a subsequent lecture.

The leaf has been described (p. 107) as an expansion of the bark. It consists internally of two layers of veins or vascular fibres laid one over the other, the upper connected with the wood—the lower with the inner bark. It is covered on both sides by a thin membrane (epidermis) the expansion of the outer bark. This thin membrane is studded with numerous small pores or mouths (stomata) which vary in size and in number with the nature of the plant, and with the circumstances in which it is intended to grow. It is from the pores in the upper part of the leaf that substances are supposed to be exhaled, while every thing that is inhaled enters by those which are observed in the under side of the leaf.[‡] This opinion, however, is not universally received, it being admitted by some that the power both of absorbing and of emitting may be possessed by the under surface of the leaf.

[†] Chlorine is a gas of a greenish yellow colour, having an unpleasant taste and a suffocating odour. When it combines with other substances it forms *chlorides*. It exists in, and imparts its smell to, *chloride of lime*, which is employed for disinfecting purposes, and it forms upwards of half the weight of common salt.

[†] *Three Lectures on Agriculture*, p. 59.

[‡] This is illustrated by the action of a cabbage leaf on a wound. If the upper side be applied, the sore is protected and quickly heals, while the under side *draws* it and produces a constant discharge.

7°. We have seen that the chief supply of the fluids which constitute the sap of plants, is derived from the soil. The under side of the leaves of plants is also supposed by some to be capable of absorbing moisture from the air, either in the form of watery vapour, or when it falls upon the leaves in the state of dew. Like the roots also they may absorb with the dew any substances the latter happens to hold in solution. And thus plants may, in some degree, be nourished by the volatile organic substances which ascend from the earth during the heat of the day, and which are again in a great measure precipitated with the evening dew.

Whether the leaves ever absorb nitrogen gas from the air has not as yet been determined with sufficient accuracy. If they do, it must in general be in very small quantity only, since it has hitherto escaped detection. In like manner it is doubtful how far they regularly absorb any other substances which the air is supposed to contain. Thus it is known that nitric acid exists in the air in very minute quantity. Some chemists also believe that ammonia is extensively diffused through the atmosphere in an exceedingly diluted state. Do the leaves of plants absorb these substances? Is the absorption of them one of the constant and necessary functions of the leaves? The reply to these questions must be very uncertain, and any principle which professes to be based upon such a reply must be regarded only as a matter of opinion.

8°. The petals or flower-leaves perform a somewhat different function from those of the ordinary leaves of a plant. They absorb oxygen at all times—though more by day than by night—and they constantly emit carbonic acid. The bulk of the latter gas evolved, however, is less than that of the oxygen taken in. The absorption of oxygen gas, and the constant production of carbonic acid, is, in some flowers, so great as to cause a perceptible increase of temperature—and to this slow combustion, so to speak, the proper heat observed in the flowers of many plants has been attributed.

According to some authors, the flower-leaves also emit pure nitrogen gas.* This fact has not yet been determined by a sufficient number of accurate experiments; it is in accordance, however, with the results of Boussingault that, when a plant flowers and approaches to maturity, the nitrogen it contains becomes less. If confirmed, this evolution of nitrogen would throw an interesting light on the most advantageous employment of green crops, both for the purposes of manure and for the feeding of cattle.

9°. When the leaves of a plant begin to decay, either naturally as in the autumn, or from artificial or accidental causes, they no longer absorb and decompose carbonic acid, even under the influence of the sun's rays. On the contrary, they absorb oxygen, like the petals of the flower, new compounds are formed within their substance—their green colour disappears—they become yellow—they wither, die, and drop from the tree—their final function, as the organs of a living being, is discharged. They then undergo new changes, are subjected to a new series of influences, and are made to serve new purposes in the economy of nature. These we shall hereafter find to be no less interesting and important in reference to a further end, than are the functions of the living leaf to the growth and nourishment of the plant.†

§ 6. *Functions of the bark.*

The inner bark being connected with the under layer of vessels in the leaf, receives from them the sap after it has been changed by the action of the air and light, and transmits it downwards to the root.

The outer bark, especially in young twigs and in the stalks of the grasses, so closely resembles the leaves in its appearance, that we can have no difficulty in admitting that it must, not unfrequently, perform similar functions. In the Cactus, the Stapelia, and other plants which produce no true leaves, this outer bark seems to perform all the functions which in other vegetable tribes are specially assigned to the abundant foliage. During its descent through the inner bark, therefore, the sap must in very many cases undergo chemical changes, more or less analogous to those which usually take place in the leaf.

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* Sprengel *Chemie*, II. p. 347.

† See subsequent lecture, "*On the law of the decay of organic substances.*"

It is by means of the inner bark that the stems of trees, such as our forest and fruit trees, are enlarged by the deposition of annual layers of new wood. The woody fibre is formed or prepared in the leaf, and as the sap descends it is deposited beneath the inner surface of the inner bark. It thus happens that, as the sap descends, it is gradually deprived of the substances it held in solution when it left the leaf, and in consequence it becomes difficult to say how much of the change, which the sap is found to have undergone when it reaches the root, is due to chemical transformations produced during its descent, and how much to the deposition of the woody fibre and other matters it has parted with by the way.

Among other evidences of such changes really taking place during the descent of the sap, I may mention an observation of Meyen (*Jahresbericht*, 1839, p. 27), made in the course of his experiments on the re-production of the bark of trees. In these experiments he enclosed the naked wood in strong glass tubes, and in three cases out of eight the tubes were burst and shattered in pieces. This could only have arisen from the disengagement of gaseous substances, the result of decomposition. While, therefore, such gases as enter by the roots or are evolved in the vessels of the wood during the ascent of the sap, escape by the leaf along with those which are disengaged in the leaf itself, it is probable that those which are produced as the result of changes in the bark, descend with the downward sap, and are discharged by the root.*

In the bark of the root it is probable that still further changes take place—and of a kind which can only be effected during the absence of light. This is rendered probable by the fact that the bark of the root frequently contains substances which are not to be met with in any other part of the plant. Thus from the bark of the fresh root of the apple tree a substance named *phloridzine*, possessed of considerable medical virtues, may be readily extracted, though it does not exist in the bark either of the stem or of the branches.

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* Sprengel says that the stems, and twigs, and the stalks of the grasses, all absorb oxygen and give off carbonic acid.—*Chemie*, II, p. 341.

In fine, as the food which is introduced into the stomachs of animals, undergoes continual and successive chemical changes during its progress through the entire alimentary canal—so, numerous phenomena indicate that the sap of plants is also subjected to unceasing transformations,—in the root and in the stem as well as in the leaves,—at one time in the dark, at another under the influence of the sun's rays,—exposed when in the leaf to the full action of the air,—and when in the root almost wholly secluded from its presence;—the new compounds produced in every instance being suited either to the nature of the plant or the wants and functions of that part of it in which each transformation takes place.

To some of these transformations it will be necessary to advert more particularly, when we come to consider the special changes by which those substances of which plants chiefly consist, are formed out of these compounds on which they chiefly live.

§ 7. *Circumstances by which the functions of the various parts of plants are modified.*

Plants grow more or less luxuriantly, and their several parts are more or less largely developed, in obedience to numerous and varied circumstances.

I. In regard to the special functions of the root, we have already seen that the access of atmospheric air is in some cases indispensable, while in others, by shooting vertically downwards, the roots appear to shun the approach of either air or light. It is obvious also that a certain degree of moisture in the soil, and a certain temperature, are necessary to the most healthy discharge of the functions of the root. In hot weather the plant droops, because the roots do not absorb water from the soil with sufficient rapidity. And though it is probable that, at every temperature above that of absolute freezing, the food contained in the soil is absorbed and transmitted more or less slowly to the stem, yet it is well known that a genial warmth in the soil stimulates the roots to increased activity. The practice of gardeners in applying *bottom* heat in the artificial climate of the green-house and conservatory is founded on this well known principle.

But the nature of the soil in which plants grow has also much influence on the way in which the functions of the root are discharged. As a general fact this also is well known, though the special qualities of the soil on which the greater or less activity of vegetation depends, are far from being generally understood. If the soil contain a sensible quantity of any substance which is noxious to plants, it is plain that their roots will be to a certain degree enfeebled, and their functions in consequence only imperfectly discharged. Or if the soil be deficient either in organic food, or in one or other of those inorganic substances which the plants necessarily require for the production of their several parts, the roots cannot perform their office with any degree of efficiency. Where the necessary materials are wanting the builder must cease to work. So in a soil which contains no silica, the grain of wheat may germinate, but the stalk cannot be produced in a natural or healthy state, since silica is indispensable to its healthy construction.

II. The ascent of the sap is modified chiefly by the season of the year, by the heat of the day, and by the genus and age of the plant or tree.

There seems reason to believe that the plant never sleeps, that even during the winter the circulation slowly proceeds, though the first genial sunshine of the early spring stimulates it to increased activity. The general increased temperature of the air does not produce this acceleration in so remarkable a manner as the direct rays of the sun. The sap will flow and circulate on the side of a tree on which the sunshine falls, while it remains sensibly stagnant on the other. This is shewn by the cutting down similar trees at more and more advanced periods of the spring, and immersing their lower extremities in coloured solutions. The wood and bark on one side of the tree will be coloured, while on the other, both will remain unstained. If a similar difference in the comparative rapidity of the circulation on opposite sides of a trunk or branch be supposed to prevail more or less throughout the year, we can readily account for the annual layers of wood being often thicker on the one half of the circumference of the stem than on the other.

The sap is generally supposed to flow most rapidly during the spring, but if trees be cut down at different seasons, and immersed as above described, the coloured solution, according to Boucherie, reaches the leaves most rapidly in the autumn.*

The heat of the day, other circumstances being the same, materially affects, for the time, the rapidity of the circulation. The more rapidly watery and other vapours are exhaled from the leaves, the more quickly must the sap flow upwards to supply the waste. If on two successive days the loss by the leaves be, as in the experiment of Hales, above described, (p. 129,) as 2 to 3, the ascent of the sap must be accelerated or retarded in a similar proportion. Hence, every sensible variation in the temperature and moisture of the air, must also, to a certain extent, modify the flow of the sap; must cause a greater or less transport of that food which the earth supplies, to be carried to every part of the plant, and must thus sensibly affect the luxuriance and growth of the whole.

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* Boucherie makes a distinction, not hitherto insisted upon by physiologists, between the circulation on the surface of the tree by which the buds and young twigs are supported, and the interior circulation which is not perfect until a later period of the year. Hence in the spring, though the sap is flowing rapidly through the bark and the newest wood, coloured solutions will not penetrate the interior of the tree with any degree of rapidity. In autumn, on the other hand—when the fear of approaching winter has already descended upon the bark—the time of most active circulation has only arrived for the interior layers of the older wood. It is this season consequently that he finds most favourable for impregnating the trunks of trees with those solutions which are likely to preserve them from decay.—*Ann. de Chim. et de Phys.* lxxiv. p. 135.

But the persistance of the leaves is a generic character, which has considerable influence upon the circulation in the *evergreens*. In the pine and the holly, from which the leaves do not fall in the autumn, the sap ascends and descends during all the colder months,—at a slower rate, it is true, than in the hot days of summer, yet much more sensibly than in the oak and ash, which spread their naked arms through the wintery air. This is illustrated by the experiments of Boucherie, who has observed that in December and January the entire wood of resinous trees may be readily and thoroughly penetrated by the spontaneous ascent of saline and other solutions, into which their stems may be immersed.

III. From what has just been stated, it will appear that the mechanical functions of the stem are subject to precisely the same influences as the ascent of the sap. As the tree advances in age, the vessels of the interior will become more or less obliterated, and the general course of the sap will be gradually transferred to annual layers, more and more removed from the centre. It is this transference of the vital circulation to newer and more perfect vessels that enables the tree to grow and blossom and bear fruit through so long a life. In animals the vessels are gradually worn out by incessant action. None of them, through old age, are permitted to retire from the service of the body—and the whole system must stop when one of them is incapacitated for the further performance of its appointed duties.

In regard to the *chemical* functions of the stem, it is obvious that they are not assigned to the mere woody matter of the vessels and cells. They take place in these vessels, but the nature and extent of the chemical changes themselves must be dependent upon the quantity and kinds of matter which ascend or descend in the sap. The entire chemical functions of the plant, therefore, must be dependent upon and must be modified by the nature of the substances which the soil and the air respectively present to the roots and to the leaves.

IV. In describing the functions of the leaf, I have already had occasion to advert to the greater number of the circumstances by which the discharge of those functions is most materially affected. We have seen that the purposes served by the leaf are entirely different according as the sun is above or below the horizon; that the temperature and moisture of the air may indeed materially influence the rapidity with which its functions are discharged—but that the light of the sun actually determines their nature. Thus the leaf becomes green and oxygen is given off in the presence of the sun, while in his absence carbonic acid is disengaged, and the whole plant is blanched.

How necessary light is to the health of plants may be inferred from the eagerness with which they appear to long for it. How intensely does the sun-flower watch the daily course of the sun,—how do the countless blossoms nightly droop when he retires,—and the blanched plant strive to reach an open chink through which his light may reach it!*

That the *warmth* of the sun has comparatively little to do with this specific action of his rays on the chemical functions of the leaf, is illustrated by some interesting experiments of Mr. Hunt, on the effect of rays of light of different colours on the growing plant. He sowed cress seed, and exposed different portions of the soil in which the seeds were germinating, to the action of the red, yellow, green, and blue rays, which were transmitted by equal thicknesses of solutions of these several colours. "After ten days, there was under the blue fluid, a crop of cress of as bright a green as any which grew in full light and far more abundant. The crop was scanty under the green fluid, and of a pale yellow, unhealthy colour. Under the yellow solution, only two or three plants appeared, but less pale than those under the green,—while beneath the red, a few more plants came up than under the yellow, though they also were of an unhealthy colour. The red and blue bottles being now mutually transferred, the crop formerly beneath the blue in a few days appeared blighted, while on the patch previously exposed to the red, some additional plants sprung up."*

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* A potatoe has been observed to grow up in quest of light from the bottom of a well twelve feet deep—and in a dark cellar a shoot of 20 feet in length has been met with, the extremity of which had reached and rested at an open window. In the leaves of blanched vegetables peculiar chemical compounds are formed. Thus in the stalk of the potatoe a poisonous substance called *solanin* is produced, which disappears again when the stalk is exposed to the light and becomes green.

Besides the rays of heat and of light, the sun-beam contains what have been called chemical rays, not distinguishable by our senses, but capable of being recognised by the chemical effects they produce. These rays appear to differ in kind, as the rays of different coloured light do. It is to the action of these chemical rays on the leaf, and especially to those which are associated with the blue light in the solar beam, that the chemical influence of the sun on the functions of the leaf is principally to be ascribed.

It cannot be doubted that the warmth and moisture of a tropical climate act as powerful stimulants—assistants it may be—to the leaf, in the absorption of carbonic acid from the air, and in that rapid appropriation (assimilation) of its carbon, by which the growth of the plant is hastened and promoted. But the bright sun, and especially the chemical influence of his beams, must be regarded as the main agent in the wonderful development of a tropical vegetation. Under this influence the growth by the leaves at the expense of the air must be materially increased, and the plant be rendered less dependent upon the root and the soil for the food on which it lives.†

V. The rapidity with which a plant grows has an important influence upon the share which the *bark* is permitted to take in the general nourishment of the whole. The green shoot performs in some degree the functions of the leaf. In vascular plants, therefore, which in a congenial climate may almost be seen to grow, the entire rind of a tall tree may more or less effectually absorb carbonic acid from the atmosphere, during the presence of the sun. The broad leaves of the palm tree, when fully developed, render the plant in a great degree independent of the soil for organic food—and the large amount of absorbing surface in the long green tender stalks of the grasses, and of their tropical analogues, must materially contribute to the same end. Hence the proportion of organic matter derived from the air, in any crop we reap, must always be the greater the more rapid its general vegetation has been.

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* *London and Edinburgh Journal of Science, February*, 1840.
Might not our cheap blue glass be used with advantage in glazing hot-houses, conservatories, &c.?

† The effect of continued sunshine may be often seen in our corn fields in May, when, under the influence of propitious weather, the young plants are shooting rapidly up. When such a field is bounded by a lofty hedge running nearly north and south, the ridges nearest the hedge on either side will be in the shade for nearly one-half of the day, and will invariably appear of a paler green and less healthy colour. If the hedge be studded with occasional large trees, the spots on which the shadows of those trees rest will be indicated by distinct pale green patches stretching further into the field than the first, and sometimes even than the second ridges.

It is a fact familiarly known to all of you, that, besides those circumstances by which we can perceive the special functions of any one organ to be modified, there are many by which the entire economy of the plant is materially and simultaneously affected. On this fact the practice of agriculture is founded, and the various processes adopted by the practical farmer are only so many modes by which he hopes to influence and promote the growth of the whole plant, and the discharge of the functions of all its parts.

Though manures in the soil act immediately through the roots, they stimulate the growth of the entire plant; and though the application of a top-dressing may be supposed first to affect the leaf, yet the beneficial result of the experiment depends upon the influence which the dressing may exercise on every part of the vegetable tissue.

In connection with this part of the subject, therefore, I shall only further advert to a very remarkable fact mentioned by Sprengel, which seems, if correct, to be susceptible of important practical applications. He states that it has very frequently been observed in Holstein, that if, on an extent of level ground sown with corn, some fields be marled, and others left unmarled, the corn on the latter portions will grow *less luxuriantly* and will *yield a poorer* *crop than if the whole had been unmarled.* Hence he adds, if the occupier of the unmarled field would not have a succession of poor crops, he must marl *his* land also.*

Can it really be that nature thus rewards the diligent and the improver? Do the plants which grow on a soil in higher condition take from the air more than their due share of the carbonic acid or other vegetable food it may contain, and leave to the tenants of the poorer soil a less proportion than they might otherwise draw from it? How many interesting reflections does such a fact as this suggest! What new views does it disclose of the fostering care of the great Contriver—of his kind encouragement of every species of virtuous labour! Can it fail to read to us a new and special lesson on the benefits to be derived from the application of skill and knowledge to the cultivation of the soil?

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* Wenn nämlich auf einer Feldflur Stück um Stück gemergelt worden ist, so wachsen die Früchte auf den nicht gemergelten Feldern, auch wenn hier alle früheren verhältnisse ganz die-selben bleiben, nicht mehr so gut, als ehedem; wodurch die Besitzer jener Felder, wenn sie nicht fortwährend geringe Erndten haben wollen, genöthigt sind, gleichfalls zu mergeln. Aus dieser höchst vichtigen Erscheinung, die man *sehr häufig* in Holsteinschen bemerkt, &c.—Sprengel *Chemie für Landwirthschaft* I. p. 303.

LECTURE VI.

Substances of which plants chiefly consist—Woody fibre, Starch, Gum, Sugars—Their mutual relations and transformations—Gluten, Vegetable Albumen, Diastase—Acetic, Tartaric, Malic, Citric, and Oxalic Acids—General observations.

From what has been stated regarding the structure of plants, it will be understood in what way the food is introduced into their circulation. The next inquiry appears to be *how*—by what chemical changes—is the food, when introduced, converted into those substances of which plants chiefly consist. But in order that we may clearly understand this point, it is necessary that we know first the nature and chemical constitution of the substances which are most largely formed from the food in the interior of the plant. To this point, therefore, I must previously direct your attention.

If you were to collect all the varieties of plants which are within your reach—whether such as are cultivated and used for food—or such as grow more or less abundantly in a wild state—and were to extract their several juices, and to separate from each of these juices the chemical compounds it contains—you would gradually gather together so many different substances, all possessed of different properties, that you would scarcely be able to number them.

But if at the same time you compared the weight of each substance thus collected with that of the entire plant from which it is derived, you would find also that the quantity of many of them is comparatively so minute that only a very small portion of the vital energies of the plant can be expended in producing them,—that they may be entirely neglected in a general consideration of the great products of vegetation. Thus though quinine and morphine, the active ingredients in Peruvian bark and in opium, are most interesting substances, from their effect upon the human constitution, and their use in medicine, yet they form so small a fraction of the mass of the entire trees or plants from which they are extracted, that it would be idle to attempt to convey to you any notion of the way in which plants grow and are fed, by shewing you how such substances as these are produced from the food on which plants live.

While, however, this examination would satisfy you that almost every species of plant produced in small quantity one or more substances peculiar to itself, you would observe, at the same time, that every plant yielded a certain quantity of two or three substances common to and produced by all, and in most cases constituting the greater portion of their bulk. Thus all trees and herbs produce wood or woody fibre, and of this substance you know that their chief bulk consists. Again, all the grains and roots you cultivate contain starch in large quantity, and the production of this starch is one of the great objects of the art of culture. The juices of trees, and of grasses, and of cultivated roots, contain sugar and gum, and sometimes in such quantity as to make their extraction a source of profit both to the grower and to the manufacturer. The flour of grain contains sugar also, and along with it two other substances, in small quantity, *gluten* and *vegetable albumen*, which are of much importance in reference to the nutritive qualities of the different varieties of flour. Sugar is also present in the juices of fruits, but it is there associated with various acid (sour) substances which disappear to a certain extent or change into sugar as the fruit ripens.

Of these few substances the great bulk of vegetables of all kinds consists. They constitute nearly the whole mass of those various crops which the art of culture studies to raise for the use of man and beast. To the study of these substances, therefore, I shall at present confine your attention, and if I shall afterwards be able to make you understand how these few compound bodies are produced in the interior of a plant from the food it takes up, I shall succeed in conveying to you as much information in regard to this most interesting branch of our subject as will be necessary to a general explanation not only of the natural growth and increase of plants, but of the nature and efficacy of those artificial means which the practical farmer employs, in order to hasten their growth or enlarge their increase.

§ 1. *Woody fibre or lignin—its constitution and properties.*

1°. When a portion of the stem of a herbaceous plant, or of the newly cut wood of the trunk or branch of a tree, is reduced to small pieces, and boiled in successive portions of water and alcohol, as long as any thing is taken up, a white fibrous mass remains, to which the name of woody fibre or lignin has been given. This substance has no taste or smell, and is perfectly insoluble in water. It is nearly identical in its chemical constitution and properties, whether it be obtained from the porous willow, or from the solid box tree, and the fibres of linen and of cotton consist essentially of the same substances.

According to the analysis of Dr. Prout, this woody fibre when dried at 350° F., consists of

	From Box Wood.	From the Willow.
Carbon	50·0	49·8
Hydrogen	5·55	5·58
Oxygen	44·45	44·62
	100	100

It will be recollected that water consists of oxygen and hydrogen, combined in the proportion, by weight, of 8 of the former to 1 of the latter. (See Lecture II., p. 42.) Now if the hydrogen above given be multiplied by 8, the product will be found to be almost exactly the weight of the oxygen given—since

$$5{\cdot}55 \times 8 = 44{\cdot}40, \text{ and}$$
$$5{\cdot}58 \times 8 = 44.64.$$

In woody fibre, therefore, the hydrogen and oxygen exist in the same proportion as in water, and its composition, therefore, might be represented by

Carbon	50·0
Water	50.0
	100

did we not know that woody fibre, when heated or distilled, cannot be resolved into carbon (charcoal) and water *alone*, and, therefore, cannot be supposed to *consist* of these alone.

It is a remarkable character of this substance, however, that these two elements, hydrogen and oxygen, exist in it in the proportions to form water, and we shall find the knowledge of this fact of great importance to us, when we come to inquire how this constituent of vegetables is formed—from the food on which they live.

2°. If a portion of the wood of a tree be dried and analyzed *without* being previously digested in water, alcohol, and ether, as long as any thing is taken up, the proportion of the constituents is found to vary slightly with the species of tree, but in all cases the hydrogen is in larger quantity than is necessary to form water with the oxygen they contain. Thus, according to Payen, the dry wood of the following trees consists of

	Ebony.	Walnut.	Oak.	Beech.
Carbon . .	52·85	51·92	50·00	49·25
Hydrogen .	6·00	5·96	6·20	6·10
Oxygen . .	41·15	42·12	43·80	44·65
	100	100	100	100

The carbon in these several kinds of wood differs as much as three per cent., but in each of them the product of the hydrogen when multiplied by 8, is considerably greater than the per centage of oxygen.

3°. When the solid substance of wood is examined under the microscope it is observed to consist of two portions or kinds of matter, that of which the original sides of the cells and tubes is composed, called the *cellular matter*—the true woody fibre—and of a solid substance by which the cells are internally coated and strengthened, called the *incrusting matter*. It is in this latter substance that the excess of hydrogen, exhibited by the preceding analysis, is supposed to exist, the true woody fibre containing always the hydrogen and oxygen in the proportions necessary to form water.*

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* Payen at first considered this *incrusting* matter as a peculiar substance, for which he proposed the name of *sclerogene*. His first mode

It is exceedingly difficult in any case to separate the cellular from the incrusting matter of wood, so as to obtain the means of determining by analysis the exact difference in their elementary constitution. Under the impression that in very light and porous substances he should obtain the cellular matter in a purer form, Payen analysed the fibre of cotton—the pith of the elder, the cellular substance of the cucumber, of the mushroom, and of other fungi, the spongy matter which forms the extremities of the roots of plants, and various other similar substances, and in all these varieties he found the hydrogen and oxygen to exist in the proportions to form water. The mean of his analyses was very nearly as follows—which for the purpose of comparison I shall contrast with that of Dr. Prout:

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of separating it from the cellular matter was by treating the finely rasped wood (of the oak and beech) with nitric acid, which dissolved out the incrusting matter and left the cellular matter behind. His second mode was to digest the wood with dilute sulphuric acid, by which the cellular matter was dissolved out, and the incrusting matter left. It is obvious, however, that no reliance whatever can be placed on the analyses of substances so treated, since they cannot fail to have undergone a chemical change by being exposed to the action of these strong acids. Further examination has satisfied Payen that the incrusting matter consists of at least *three* substances, of which one is soluble in water, alcohol, and ether, another in alcohol only, while the third is insoluble in any of these liquids. They are composed, according to his analyses, of

	Insoluble.	Soluble in alcohol only.	Soluble in water and alcohol.
Carbon . .	48	62·8	68·53
Hydrogen . .	6	5·9	7·04
Oxygen . .	46	31·3	24·43[*]
	100	100	100

It is impossible to say how far the substances analyzed by Payen are to be considered as pure, or as actually existing in the pores, or in the incrusting matter of the woody fibre, but it is obvious that the presence of a variable quantity of such substances will necessarily cause that excess of hydrogen, in the entire wood, which appears in the analysis of the ebony, walnut, oak, and beech woods, given in the text. That such an excess of hydrogen above what is necessary to form water with the oxygen, does exist in the wood of most trees in its natural state, is a fact to which it will be important to advert when we consider hereafter the chemical changes which the food undergoes in the interior of the plant.

[* Meyen's *Jahresbericht*, 1839, p. 10.]

	Woody fibre of box and willow—Dr. Prout.	Cellular matter of vascular plants—Payen.
Carbon	50·00	44·80
Hydrogen	5·55	6·20
Oxygen	44·45	49·0
	100	100*

In both these analyses the hydrogen is very nearly 8 times that of the oxygen. All these substances, therefore, may be represented by carbon and water, though the woody fibre of Dr. Prout contains 5 per cent. more carbon than the cellular matter of Payen.

If we calculate the number of equivalents of each element contained in these two varieties† of vegetable fibre composed as above exhibited, we find in the one 12 of carbon, 8 of hydrogen, and 8 of oxygen; in the other, 12 of carbon, 10 of hydrogen, and 10 of oxygen. They may, therefore, be conveniently represented by the following formulæ:

Woody Fibre . . . . . by $C^{12} H^{8} C^{8}$
Cellular Fibre . . . . by $C^{12} H^{10} C^{10}$

It is not unlikely that both of these forms of matter may exist, as well in the perfect wood of trees as in the less consolidated pith of the elder, or in the fibres of cotton—and that they may occur intermingled also in varying proportions with other substances, containing hydrogen in excess.‡

I have spoken of these varieties of woody fibre as constituting a large portion of the entire mass of vegetable matter

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* Meyen's *Jahresbericht*, 1839, p. 10.

† This is done very simply by dividing the carbon by 6, and the oxygen by 8 (see page 42), thus—

Carbon . . .	50 ÷ 6 = 8·33	which numbers are to each other as	12
Hydrogen . .	5·55 = 5·55		8
Oxygen . . .	44·45 ÷ 8 = 5·55		8

‡ The existence of a variety of cellular fibre identical in constitution with common starch, as this of Payen is, (see subsequent section, p. 155) was previously rendered probable by the observations of Dr. Schleiden, that the embryo of the *Schotia latifolia*, consisting of pores and vessels, the sides of which exhibit distinct concentric layers, is entirely soluble in water, with the exception of the outer rind; and that its solution becomes blue on the addition of iodine. It would appear as if the cellular substance were in this case wholly composed of Starch. (*Poggendorf's Annalen*, xliii. p. 398.) It may, however, be in such a state of tenuity in

produced during the growth of plants. That such is the case in the more gigantic vegetable productions, of which the great forests consist, is sufficiently evident, and so far the general statement is easily seen to be correct. It is also true of the dried stalks of the grasses and the corn-growing plants, of which it forms nearly one-half the weight,—but in roots and in some plants which are raised for food, the quantity of woody fibre, especially in the earlier stages of their growth, is comparatively small.* Thus in the beet root it forms only 3 per cent. of the whole weight when taken from the ground. If suffered to remain in the soil till it be-

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the embryo of this plant, as to be easily changed into starch by the action of hot water; and it is still by no means certain that the cellular fibre analyzed by Payen may not also have undergone a change by the treatment to which it was previously subjected. I am unable, however, to speak decidedly on this subject, as I have not seen the details of M. Payen's several papers. (See subsequent section, *on the mutual transformations of woody fibre, starch, gum, and sugar*, p. 163.)

* The following table shews the per centage of woody fibre contained in some common plants in the green state, and when dried in the air, and at 212°:

			IN THE GREEN STATE.	
	Dried in the air. per cent.	Dried at 212°. per cent.	Woody fibre. per cent.	Water. per cent.
Barley straw, ripe	50	—	—	—
Oat straw, do.	—	47	—	—
Maize straw, do.	24	—	—	—
Stalks of the field pea . . .	—	—	10⅓	80
Field bean straw, . . .	51	—	—	—
White turnip	—	—	3	92
Common beet (beta vulgaris) .	—	—	3	86
Young twigs of common furze .	—	—	24	50
Rape straw, ripe	—	55	12⅓	77
Tare straw, do.	37	—	—	—
Vetch plant (v. sativa) . .	42	—	10⅓	77½
Do. (v. cracca) in flower	—	—	5½	68
Do. (v. narbonensis) do.	—	—	11½	80
White lupin, in flower, . .	—	—	7	86
Lucerne, in flower, . . .	—	—	9	73
Rye grass, do. . . .	—	—	11	68
Red clover, do. . . .	—	—	7	79
White clover. do. . . .	—	—	4½	81
Trefoil (medium) do. . . .	—	—	8½	73
Sainfoin (esparsette) . . .	—	—	7	76
Trefoil (agrarium) in flower .	—	—	12	68
Do. (rubens) do. . .	—	—	15	60

comes old, or if the growth be very slow, the beet becomes more woody, as many other roots do, and the quantity of ligneous fibre increases.

§ 2. *Starch—its constitution and properties.*

Next to woody fibre, starch is probably the most abundant product of vegetation. To the agriculturist it is a substance of much more interest and importance than the woody or cellular fibre, from the value it possesses as one of the staple ingredients in the food of man and animals—and from its forming a large portion of the weight of the various grains and roots which are the principal objects of the art of culture.

1°. When the flour of wheat, barley, oats, Indian corn, &c., is mixed up into a dough with water, and this dough washed on a linen cloth with pure water, a milky liquid passes through, from which, when set aside, a white powder gradually falls. This white powder is the *starch* of wheaten or other flour.

2°. When the pith of the sago palm is washed, in a similar manner, with water upon a fine sieve, a white powder is deposited by the milky liquid which passes through. This, when collected, forced through a metal sieve to granulate (or corn) it, and dried by agitation over the fire, is the *sago* of commerce.

3°. When the raw potatoe is peeled and grated on a fine grater, and the pulp thus produced well washed with water, *potatoe starch* is obtained in the form of a fine white powder, consisting of rounded, glossy and shining particles.

4°. When the roots of the *Maranta Arundinacea* of the West India Islands are grated and washed like the potatoe, they yield the *arrow root* of commerce. From the root of the Manioc, the *cassava* is procured by a similar process, and this, when dried by agitation on a hot plate, is the *tapioca* of the shops. By this method of drying, both sago and tapioca undergo a partial change, which will be explained in a subsequent section (see p. 165.)

The substances to which these several names are given are, when pure, similar in their properties, and identical in their chemical constitution. They are all colourless, tasteless, without smell, when dry and in a dry place may be kept for any length of time without undergoing alteration, are insoluble in cold water or alcohol, dissolve readily in boiling water, giving a solution which gelatinizes (becomes a jelly) on cooling—and in a cold solution of iodine* they all become blue.

When dried at 212°, they consist, according to Dr. Prout, with whose analysis those of other chemists agree, of

Carbon . . .	44·0 per cent.,	or 12 atoms.
Hydrogen . . .	6·2 per cent.,	or 10 atoms.
Oxygen . . .	49·8 per cent.,	or 10 atoms.
	100	

Starch, therefore, may be represented by the formula $C^{12} H^{10} O^{10}$, which is identical with that deduced in the preceding section for the *cellular fibre* of Payen. Both substances, therefore, contain the same elements (carbon, hydrogen and oxygen), united in the same proportions, and in both, as well as in the common fibre of wood, the hydrogen and oxygen exist in the proportion to form water.

That starch constitutes a large portion of the weight of grains and roots, usually grown for food, will appear from the following table, which exhibits the quantity present in 100 lbs. of each substance named:

	Starch per cent.
Wheat flour	39 to 77
Rye do.	50 to 61
Barley do.	67 to 70
Oatmeal	70 to 80
Rice flour	84 to 85
Maize do.	77 to 80
Buck wheat	52
Pea and Bean meal	42 to 43
Potatoes, containing 73 to 78 of water, .	13 to 15

It thus exists most largely in the seeds of plants, and in some roots. It is frequently deposited, however, among the woody fibre of certain trees, as in that of the willow, and in the inner bark of others, as in those of the beech and the pine.* Hence the readiness with which a branch of the willow takes root and sprouts, and hence also the occasional use of the inner bark of trees for food, especially in northern countries, and in times of scarcity. In some roots which abound in sugar, as in those of the beet, the turnip, and the carrot, only 2 or 3 per cent. of starch can be detected.

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* Iodine is a solid substance, of a lead-grey colour, possessed of a peculiar powerful odour, and forming when heated a beautiful violet vapour. It exists in small quantity in sea water, and in some marine plants. Its solution in water readily shews the presence of starch, by the blue colour it imparts to it.

§ 3. *Gum—its constitution and properties.*

The variety of gum with which we are most familiar is *gum arabic*, or *senegal*, the produce of various species of *acacia*, which grow in the warmer regions of Asia, Africa, and America. It exudes from the twigs and stems of these trees, and collects in rounded more or less transparent drops or tears. It is also produced in smaller quantities in many of our fruit trees, as the apple, the plum, and the cherry; it is present in some herbaceous plants, as in the althaea and malva officinalis (common and marsh mallow); and it exists in lint, rape, and many other seeds. When treated with boiling water these plants and seeds give mucilaginous solutions.

Many varieties of gum occur in nature, but they are all characterised by being insoluble in alcohol, by dissolving or becoming gelatinous in hot or cold water, and by giving *mucilaginous*—viscid and glutinous—solutions, which may be employed as a paste.

Three distinct species of gum have been recognised by chemists.

1°. *Arabin*—of which gum arabic and gum senegal almost entirely consist. It is *readily soluble in cold water*, giving a viscid solution, usually known by the name of the *mucilage* of gum arabic.

2°. *Cerasin*—which exists in the gum of the cherry-tree. It is *insoluble in cold water*, but *dissolves readily in boiling*

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* Its presence is readily detected in such wood by a drop of the solution of iodine—which gives a permanent blue to starch, but to the woody fibre only a brownish stain.

water. When thus dissolved it may be dried without losing its solubility, and is therefore by boiling supposed to be changed into arabin.

3°. *Bassorin*—existing in what is called *bassora gum*—and forming a large portion of gum tragacanth.* It *swells and becomes gelatinous in cold water, but does not dissolve in water either cold or hot.*

By these characters, the three kinds of gum are not only readily distinguished, but may be easily separated from each other. Thus if a native gum or an artificial mixture contain all the three, simple steeping in and subsequent washing with *cold* water, will separate the *arabin*—boiling water will then take up the *cerasin*, and the *bassorin* will remain behind.

These different kinds of gum all possess the same chemical constitution.

According to the analyses of Mulder, they consist of

Carbon . . .	45·10	per cent., or 12 atoms.
Hydrogen . . .	6·10	per cent., or 10 atoms.
Oxygen . . .	48·80†	per cent., or 10 atoms.
	100	

In these analyses, as in those of starch and woody fibre, we see that the per centage of oxygen is equal to that of the hydrogen multiplied by 8, and consequently that these two elements are, as already stated, in the proportion to form water. But we see also that the carbon is in the proportion of 12 atoms or equivalents to 10 of each of the other constituents, and therefore gum may be represented by $C^{12} H^{10} O^{10}$—a formula which is identical with that already given for starch and cellular fibre.

It appears, therefore, that not only may *gum*, *starch*, and *cellular fibre* be represented by carbon and water, but that they *all consist of carbon and the elements of water, united together in the same proportions.*

Gum not only exists in many seeds, and exudes as a natural product from the stems and twigs of many trees, but is also contained in the juices of many other trees, from which it is not known to exude; and in the sap of most plants it may be detected in greater or less quantity. It may be considered, indeed, as one of those substances which are produced most largely and most abundantly in the vegetable kingdom, since, as will hereafter appear, it is one of those forms of combination through which organic matter passes in the interesting series of changes it undergoes during the development and growth of the plant.

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* This gum exists along with starch in the roots of the various species of *orchis*, especially of those which are used for making *salep* (Meyen).

† Berzelius *Årsberättelse*, 1839, p. 443.

§ 4. *Of Sugar—its varieties and chemical constitution.*

1°. *Cane Sugar.*—Sugar, identical in constitution and properties with that obtained from the sugar-cane, and generally known by the name of *cane*-sugar, exists in the juices of many trees, plants, and roots. In the United States of North America the juice of the maple tree is extensively collected in spring, and when boiled down yields an abundant supply of sugar. In the Caucasus that of the walnut is extracted for the same purpose. The juice of the birch also contains sugar, and it may be obtained, in lesser quantity, from the sap of many other trees. In the juice of the turnip, carrot, and beet, it is also present, and in France and Germany the latter root is extensively cultivated for the manufacture of beet sugar. In the unripe grains of corn, at the base of the flowers of many grasses and clovers when in blossom, and even in many small roots, as in that of the quicken or couch-grass (triticum repens), the presence of sugar may likewise be readily detected.

Sugar is principally distinguished by its agreeable sweet taste. When pure, it is colourless and free from smell. It dissolves readily in alcohol and in large quantity in water. The solution in water, when much sugar is present, has an oily consistence, and is known by the name of *syrup*. From this syrup the sugar gradually deposits itself in the form of crystals of *sugar candy*. If the syrup be boiled on too hot a fire, it chars slightly, becomes discoloured, and a quantity of *molasses* is formed. Pure *cane*-sugar, free from water, consists of

Carbon . . .	44·92 per cent.,	or 12 atoms.
Hydrogen . . .	6·11 "	or 10 "
Oxygen . . .	48·97 "	or 10 "
	100	

If we compare these numbers with those given for starch and gum in the preceding sections, we see that they are almost identical—so that cane-sugar also contains oxygen and hydrogen in the proportions to form water, and may likewise be represented by the formula $C^{12} H^{10} O^{10}$.

2°. *Grape sugar.*—In the juice of the grape a peculiar species of sugar exists, which, in the dried raisin, presents itself in the form of little rounded grains. The same kind of sugar gives their sweetness to the gooseberry, the currant, the apple, pear, plum, apricot, and most other fruits. It is also the sweet substance of the chesnut, of the brewers' wort, and of all fermented liquors, and it is the solid sugar which floats in rounded grains in liquid honey, and which increases in apparent quantity as the honey, by keeping, becomes more and more solid.

Grape sugar has nearly all the sensible characters of cane sugar, with the exception of being less soluble in water and also less sweet,—2 parts of the latter imparting an equal sweetness with 5 of the former.

In chemical constitution they differ considerably. Thus grape sugar dried at 250° F., consists of

Carbon . . .	40·47 per cent.,	or 12 atoms.
Hydrogen . . .	6·59 "	or 12 "
Oxygen . . .	52·94 "	or 12 "
	100	

The oxygen here is still eight times greater than the hydrogen, and, therefore, in this variety of sugar also, these elements exist in the proportions to form water. But for every 12 equivalents of carbon dry grape sugar contains 12 of hydrogen and 12 of oxygen. It is consequently represented by $C^{12} H^{12} O^{12}$, and contains the elements of two atoms of water ($H^2 O^2$) more than cane sugar.*

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* Solutions of cane and grape sugar are readily distinguished from each other by the following chemical characters:—1. If the solution be heated and a few drops of sulphuric acid then added, cane sugar will be

3°. *Manna sugar, sugar of liquorice, &c.*—Besides the cane and grape sugars which occur in large quantity in the juices of plants, there are other varieties which occur less abundantly, and are therefore of less interest in the study of the general vegetation of the globe. Among these is *manna*, which partly exudes and is partly obtained by incisions from certain species of the *ash* tree which grow in the warmer countries of Southern Europe (Sicily and Italy), and in Syria and Arabia. It also exists, it is said, in the juice of the larch tree, of common celery, and of certain trees which are met with in New South Wales. Liquorice root also contains a species of *black* sugar, which is known in this country under the names of Spanish and Italian juice, from the countries where it is grown. In the mushroom and other *fungi* a colourless variety, apparently peculiar, has also been met with,—and milk owes its sweetness to a species of sugar formed in the interior of the animal along with the other substances which the milk contains.

These several kinds of sugar differ more or less, not only in sensible and chemical properties, but also in chemical constitution from the more abundant cane and grape sugars —but they form too small a part of the general products of vegetation, and are of too little consequence in practical agriculture to render it necessary to do more than thus shortly advert to their existence.*

§ 5. *Mutual relations of woody fibre, starch, gum, and sugar.*

It may be interesting now to consider for a moment the mutual relations of the several substances, woody fibre, starch, gum, and sugar—above described—which occur so largely in the vegetable kingdom, and are serviceable to man for so many different purposes. These relations will be

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decomposed, blackened, and made to fall as a black or brown powder—while a solution of grape sugar will at the most be only slightly discoloured. 2. If instead of sulphuric acid, caustic potash be employed, the cane sugar will be unchanged, while the grape sugar will be blackened and thrown down.

* For a list of plants from which sugar has been extracted, see Thomson's *Organic Chemistry* (1838), p. 647.

best seen on comparing the formulæ by which they are respectively represented. Thus—

Woody Fibre	(lignin) is represented	by	$C^{12} H^{8} O^{8}$
Cellular Fibre	(according to Payen)	by	$C^{12} H^{10} O^{10}$
Starch	(dried at 212° F.)	by	$C^{12} H^{10} O^{10}$
Gum	(any of the 3 varieties)	by	$C^{12} H^{10} O^{10}$
Cane Sugar	(free from water)	by	$C^{12} H^{10} O^{10}$*
Grape Sugar	(dried at 130° F.)	by	$C^{12} H^{12} O^{12}$†

In these formulæ we observe—

1°. That the equivalents of the oxygen are equal to those of the hydrogen in *all* the formulæ, and, therefore, that all these substances may be *supposed* to consist of carbon and water.

2°. The formulæ for cellular fibre, starch, gum, and cane sugar are identical. *They consist of the same elements united together in the same proportions.*

This is one of those facts which not only appear very remarkable to the unlearned, but are scarcely capable of being clearly comprehended and explained, even by those who have most profoundly studied this branch of natural science. Starch and sugar—how different their properties! how unlike their uses! how unequal their importance to the human race! yet they consist of the same weights of the same substances, differently conjoined. The skilful architect can put together the same proportions of the same stone and cement —and the painter can combine the same colours so as to produce a thousand varied impressions on the sense of sight. In the hand of Deity matter is infinitely more plastic. At His bidding the same particles can unite in the same quantity so as to produce the most unlike impressions—and on *all* our senses at once.

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* For a list of plants from which sugar has been extracted, see Thomson's *Organic Chemistry* (1838), p. 647.

† Crystallized cane sugar (sugar candy) loses 5·3 per cent. of water in favourable circumstances. This is equal to one equivalent (H O), so that if dry sugar be $C^{12} H^{10} O^{10}$, crystallized sugar is $C^{12} H^{11} O^{11}$—or $C^{12} H^{10} O^{10} + H O$, since there is no doubt that this one equivalent of the hydrogen and oxygen exist in crystallized sugar in the state of water. In like manner, crystallized honey or grape sugar—as it occurs in honey or in the dried grape—loses 9 per cent. of water when heated to 250° F. This is equal to two equivalents (2 H O), so that crystallized grape sugar is represented by $C^{12} H^{14} O^{14}$ or $C^{12} H^{12} O^{12} + 2HO$.

3°. A knowledge of the above close relations in composition, among a class of substances occurring so abundantly in the vegetable kingdom, imparts a degree of simplicity to our ideas of this otherwise complicated subject. It does not appear so mysterious that we should have woody fibre, and starch, and gum, and sugar, occurring together in variable quantities, when we know that they are all made up of the same materials, in the same or nearly the same proportions—or that one of these should occasionally disappear from a plant, to be replaced in whole or in part by another.

A further question, however, arises in our minds. We naturally ask,—does nature, in thus removing one of these compounds, and supplying its place by another, actually form from its elements the new substance introduced, or does she produce it by a mere change or transformation of those previously existing, A satisfactory reply to this question may be derived from the facts detailed in the following section.

§ 6. *Mutual transformations of woody fibre, starch, gum, and sugar.*

I.—WOODY FIBRE.

Action of heat.—If wood be reduced to the state of fine saw-dust, be then boiled in water to separate every thing soluble, afterwards dried by a gentle heat, and then heated several times in a baker's oven, it will become hard and crisp, and may be ground in the mill into a fine meal. The powder thus obtained is slightly yellow in colour, but has a taste and smell similar to the flour of wheat; it ferments when made into a paste with yeast or leaven, and when baked gives a light homogeneous bread. Boiled with water, it yields a stiff tremulous jelly, like that from starch (Autenrieth.)* By the agency of heat, therefore, it appears that the *woody fibre may be changed into starch.*

2°. *Action of sulphuric acid.*—If to three parts of the sulphuric acid of the shops (oil of vitriol) one part of water be added, and a portion of delicate woody fibre be immersed in it for half a minute, and the whole then rubbed in a mortar with a few drops of a solution of iodine—the woody fibre will assume a *blue colour*, shewing that it is in part at least *changed into starch** (Schleiden).

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* Schübler, *Agricultur Chemie*, i., p. 224.

Again, if three-parts of fine saw-dust or of fragments of old linen be rubbed in a mortar with four of the sulphuric acid of the shops added by degrees—it will, in a quarter of an hour, be rendered completely soluble in water. If the solution in water be freed from acid by chalk, and then evaporated, a substance resembling gum arabic is obtained (Braconnot). According to Schleiden, the fibre may be seen under the microscope gradually to change from without inwards, first into starch and then into gum.

Further, if this gum be digested with a second portion of sulphuric acid diluted with 8 or 10 times its weight of water, it will be gradually converted into *grape-sugar;* or the fibre of wood or linen may be changed directly into sugar by the prolonged action of dilute sulphuric acid.

3°. *Action of Potash.*—If saw-dust be mixed with from two to eight times its weight of hydrate† of potash and as much water, and boiled till a crust forms on the surface, and if dilute sulphuric acid be then added till the whole is slightly sour, the undestroyed woody fibre will give an instantaneous deep blue on the addition of iodine, shewing that starch has been formed.

Woody fibre, therefore, may be changed into starch, either by the unaided action of heat, by that of sulphuric acid, or by boiling with caustic potash,—and the starch thus produced may be further transformed, first into gum and then into grape-sugar, by the prolonged action of dilute sulphuric acid, assisted by a moderate heat.

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* It will be recollected that starch is characterised by giving a blue colour with a solution of iodine (see p. 156).

The simplest way of trying this experiment is, to take a quantity of clean cotton—to wet it with water, squeezing out again as much as possible—then to spread it out upon a flat dish and moisten it quickly and thoroughly with the acid diluted as above. After half a minute, add the solution of iodine, stir quickly with a glass rod, and immediately add water, when the blue compound of iodine and starch will speedily deposit itself.—(Schleiden *Pog. Annal.* xliii. p. 396).

† Hydrate of potash is the caustic substance which is obtained by boiling common pearl-ash with quick-lime.

II.—STARCH.

1°. *Action of heat.*—When flour, potatoe, or arrow-root starch is spread out upon a tray, then introduced into an oven and gradually heated to a temperature not exceeding 300° F., it slowly changes, acquires a yellow or brownish tint according to the temperature employed, and becomes entirely soluble in cold water. *It is changed into gum.* Under the names of starch-gum, or British-gum, this substance is largely manufactured in this country, and is successfully substituted for gum arabic by the calico-printers in thickening many of their colours.*

The gum thus prepared not unfrequently also possesses a sweet taste, from the further change of a portion of the gum into sugar.

2°. *Action of water.*—When starch is dissolved in boiling water, and is then allowed to stand in the cold either in a close vessel or exposed to the air, it gradually changes into gum or sugar. The process however, is slow, and months must elapse before the whole of the starch is thus spontaneously transformed in the presence of water (De Saussure). It takes place more rapidly when starch and water are boiled together for a length of time.

3°. *Action of sulphuric acid.*—From what has been already stated in regard to the action of this acid on woody fibre it will readily be supposed that native starch, of any variety, is likely to undergo transformation when subjected to its influence.

In reality, if 50 parts of starch, 12 of sulphuric acid, and 139 of water be taken, and if the starch be thoroughly moistened with a portion of the water, and then poured into the mixture of the acid with the remainder of the water, and heated to 190° F., the starch will be entirely converted into gum. By further and more prolonged heating this gum is changed into grape sugar. The gum or sugar may be obtained in a separate state by adding to the solution either chalk or lime, which will combine with and carry down the acid.* One hundred pounds of starch treated in this way will yield from 105 to 122 lbs. of dry grape sugar.

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* During the baking of bread this conversion of starch into gum takes place to a considerable extent. Thus Vogel found that flour which contained no gum gave, when baked, a bread of which 18 per cent., or nearly one-fifth of the whole weight, consisted of gum. Thus one of the effects of baking is to render the flour-starch more soluble, and therefore (?) more easily digestible.

The rapidity with which this transformation takes place depends partly upon the temperature and partly upon the proportion of acid employed. Thus 100 lbs. of starch mixed with 600 of water and 10 of sulphuric acid, will be converted into grape sugar by boiling for *seven* hours. If by increasing the pressure the temperature be raised to 250° F., the transformation will be effected in a *few minutes*. With only one pound of acid and the same quantity of starch and water, the change will be effected in *three* hours by a temperature of 230° F. This mode of converting potatoe starch into grape sugar is said to be extensively practised in France, for the purpose of subsequently fermenting the sugar and converting it into *brandy*.

III.—GUM.

Action of sulphuric acid.—If powdered gum arabic be rubbed in a mortar with the sulphuric acid of the shops, a brownish solution is obtained, which, when diluted with water and treated with chalk, yields a gummy substance similar to that obtained in the same way from starch and woody fibre. Prolonged digestion with diluted acid converts a portion of this gum into sugar.†

IV.—CANE SUGAR.

1°. *Action of heat.*—When crystallized cane sugar is heated to 320° F. it melts, and if the temperature be raised to 360° F. it gives off two atoms of water and is changed into *caramel*. This caramel is an uncrystallizable sugar, which is generally present in artificial syrups, and is often of a brownish colour. It contains the elements of an atom of water less than cane sugar, and is represented by $C^{12} H^{9} O^{9}$. It is not known to occur in the natural juices of plants.

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* It forms *gypsum* with it (sulphate of lime), which is a compound of lime and sulphuric acid.

† Berzelius, *Traité de Chemie* (1831), v., p. 217.

2°. *Action of sulphuric acid.*—When cane sugar is digested with dilute sulphuric acid, aided by a gentle heat, it is rapidly converted into grape sugar. The acid of grapes (tartaric acid) and many other vegetable acids produce a similar change.

It is obvious that this conversion of cane into grape sugar can only take place in the presence of water, inasmuch, as has already been shewn (p. 161), grape sugar contains the elements of two atoms of water more than cane sugar, or

$$\underset{\text{Cane sugar.}}{C^{12} H^{10} O^{10}} + \underset{\text{Water.}}{2HO} = \underset{\text{Dry grape sugar.}}{C^{12} H^{12} O^{12}}.$$

We may revert now to the question with which we concluded the preceding section. Since these different substances are so closely allied in chemical constitution, and occur so often in connection with each other in the vegetable kingdom, does nature, when her purposes demand the change, actually transform them, the one into the other, in the interior of the plant? The answer may now be safely given, that she certainly does. What we can so readily perform by our rude art may be still more easily effected in the living vegetable. That which is starch or gum in one part of the plant, may become cane or grape sugar in another, and woody fibre in a third. Thus by re-arranging the same kind and quantity of the several elements, may the various and unlike forms of matter which constitute the main products of vegetation be readily produced.

Still the facility is only apparent. We can assure ourselves of the fact of such conversions, because we can at will induce them. But who operates upon these substances in the interior of the plant? Whose mind and will directs these changes—prescribing when, where, and in what order they shall take place? How much depends upon the refined and little understood mechanism of the vegetable structure—how much on the living principle itself! What is this living principle—how can *it* direct![*]

§ 7. *Of the fermentation of starch and sugar—and of the relative circumstances under which cane and grape sugars generally occur in nature.*

It will be of use to us, in connection with the above transformations, to advert to the property possessed by starch and nearly all the known varieties of sugar of entering into fermentation under favourable circumstances. When flour is made into a paste with leaven or yeast it begins to rise and ferment,—sooner or later, according to the kind of flour and the quantity of ferment added. When to a decoction of malt or to a solution of starch or of cane or grape sugar in water a portion of yeast is added, fermentation is speedily induced; and if not arrested by unfavourable circumstances it will continue until the whole of the starch or sugar disappears.

In all these cases it is grape sugar alone that undergoes fermentation.[†] The starch of the moist dough or of the solution is partially transformed into grape sugar before fermentation commences. Such is the case also with the decoction of malt and with cane sugar. The fermentation commences soon after the first portion of grape sugar is formed, and proceeds more or less rapidly according as this transformation is more or less speedily effected. Hence, in the art of brewing, the necessity of cautiously regulating the temperature by which this change of the starch and sugar is promoted and hastened.

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[*] "Canst thou by searching find out God—Canst thou find out the Almighty unto perfection?"

[†] Rose, *Poggen. Annal.*, lii. p. 297.

The fermentation itself is the result not of a mere *transformation* of one form of matter into another having the same elementary constitution, but of a *decomposition* of one substance into two others unlike itself either in properties or in chemical composition. The grape sugar is resolved into alcohol (spirits of wine), which remains in the liquid, and into carbonic acid, which escapes in the form of gas and causes the fermentation. Thus alcohol being represented by $C^4\ H^6\ O^2$, and carbonic acid by CO^2,

$$\begin{array}{lll} \text{2 of alcohol} & = C^8\ H^{12}\ O^4 & \text{and} \\ \text{4 of carbonic acid} & = C^4\ \phantom{H^{12}}\ O^8 & \text{make up} \\ \hline \text{1 of grape sugar} & = C^{12}\, H^{12}\, O^{12}. & \end{array}$$

It is an interesting fact that the cane and grape sugars occur in nature in circumstances which are entirely consistent with the statement in the preceding section, regarding the action of acids on the former variety of this natural product. Fruits contain grape sugar, which increases in quantity as they ripen or become less sour. In the sugar cane, the beet root, and the maple and birch trees, cane sugar exists, but in their juices no acid is associated with the sugar. On the contrary, ammonia is known to be present in most of them along with the cane sugar. Hence it is inferred, that as in our hands and in our experiments cane sugar is changed by the agency of acids into grape sugar, and with remarkable ease by that acid which exists in the ripe grape, so it is in the interior of plants. Where sugar occurs in connection with an acid in the juice of a plant, it is grape sugar in whole or in great part, because in the presence of an acid body cane sugar cannot permanently exist, but is gradually transformed into the sugar of grapes. It thus appears also why fruits so readily enter into fermentation, and why, even when preserved with cane sugar, they will, in consequence of the acid they retain, slowly change the latter into grape sugar, and thus induce fermentation.*

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* Milk also, in favourable circumstances, as when kept at a temperature of 100° F., undergoes fermentation, and in some countries of Asia a spirituous liquor is prepared from mares' and asses' milk. In this case the milk first becomes sour, then the acid thus formed converts the

§ 8. *Of substances which contain Nitrogen.—Gluten, Vegetable Albumen, and Diastase.*

The substances described in the preceding sections consist of carbon, hydrogen, and oxygen only, and of them the great bulk of the vegetable productions of the globe consists. But there are certain other substances occurring along with starch and sugar, into which nitrogen enters as a constituent, and which, though not formed in the vegetable kingdom in very large quantity, are yet of such interest and importance in other respects, as to make it necessary shortly to advert to them.

1°. *Gluten.*—When the flour of wheat is made into a dough, and this dough is washed with water upon a fine sieve, a milky liquid passes through, from which starch gradually subsides. This has been already stated. But on the sieve, when the water ceases to go through milky, there remains a soft adherent, tenacious and elastic substance, which can be drawn out into long strings, has scarcely any colour, taste, or smell, and is scarcely diminished by washing either with hot or with cold water. This substance is the *gluten* of *wheat*. The flour of other kinds of grain also yield it by a similar treatment, though generally in much smaller quantity. This appears from the following table:—

The grain of

Wheat contains	8 to 35	per cent.	of gluten.
Rye	9 to 13	"	"
Barley	3 to 6	"	"
Oats	2 to 5	"	"

When the moist gluten is dried in the air or at the temperature of boiling water, it diminishes much in bulk, and hardens into a brittle semi-transparent yellow substance resembling horn or glue. In this state it is insoluble in water,

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milk sugar into grape sugar, and finally this sugar enters into fermentation. This takes place more readily in consequence of the presence of the decomposing cheesy matter (casein) of the milk—as is shewn by the fact that the introduction of a small quantity of the curd of milk into a solution of grape sugar will cause it to ferment.

but dissolves readily in vinegar, in alcohol either cold or hot, and in solutions containing caustic* potash, or soda.

2°. *Vegetable albumen.*—To the white of egg the name of albumen (*albus* white) has been given by chemists. It possesses the well known property of coagulating or of forming a white solid insoluble substance, when it is heated either alone or after being mixed with water.

When the starch has subsided from the milky liquid which passes through the sieve in preparing the gluten of wheat, the water rests transparent and colourless above the white sediment. If this water be heated, it will become more or less troubled, and white films or particles will separate, which may be easily collected, and which possess all the properties of coagulated albumen, or boiled white of egg. To this substance the name of *vegetable albumen* has been given. When the fresh prepared *gluten* of wheat is boiled in alcohol a portion of albumen generally remains undissolved, shewing that water does not completely wash it out from the gluten.

Vegetable albumen, when fresh and moist, has neither colour, taste, nor smell, is insoluble in water or alcohol, but dissolves in vinegar and in caustic potash or soda. When dry it is brittle, more or less coloured, and opaque. In the seeds of plants, it exists only in small quantity—thus the grain of

Wheat contains	$\frac{3}{4}$ to	$1\frac{1}{2}$	per cent.
Rye	2 to	$3\frac{3}{4}$	"
Barley	$\frac{1}{10}$ to	$\frac{1}{2}$	"
Oats	$\frac{1}{5}$ to	$\frac{1}{2}$	"

It occurs more largely however in the fresh juices of plants, in those of cabbage leaves, turnip roots, and many others. When these juices are heated the albumen coagulates and is readily separated.

Gluten and vegetable albumen appear to be as closely related as sugar and starch are to each other. Like these two substances, they consist of the same elements, united together in the same proportions, and are capable of similar mutual transformations. According to the most recent analyses, those of Dr. Scheerer, they consist of

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* The common *pearl-ash* or *soda* of the shops boiled with quick-lime.

Carbon = 54·76
Hydrogen = 7·06
Oxygen = 20·06
Nitrogen = 18·12

100

When exposed to the air in a moist state these substances undergo decomposition. They ferment, emit a most disagreeable odour, and produce, among other compounds, vinegar and ammonia.

The important influence which gluten and vegetable albumen are supposed to exercise over the nourishing properties of the different kinds of food in which they occur, will be considered in a subsequent part of these lectures.*

3°. *Diastase.*—When cold water is poured upon barley newly malted and crushed, is permitted to remain over it for

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* There occur in the animal kingdom—in the bodies of animals—three other forms of the substance above described under the names of gluten and vegetable albumen. These are albumen or white of egg, already mentioned,—*casein*, the curd of cheese,—and *fibrin*, the substance of the muscular fibre of animals.

1°. *Casein.*—When the curd of cheese is well washed with water, and then boiled in alcohol to free it from oily matter, it forms the casein of chemists. While moist it is soft and colourless, but as it dries it hardens, assumes a yellow colour, and becomes semitransparent. Even when moist it is perfectly insoluble either in cold or in hot water. It is soluble, however, in water containing vinegar; or to which a little carbonate of potash or soda has been added. It may be kept for any length of time in a dry place, without undergoing decay. The changes undergone by old cheese are chiefly due to the oily and other substances with which the curd is mixed. It has been remarked, that when the gluten of wheat is left for a length of time in a moist state it undergoes a kind of fermentation and gradually acquires the smell and taste of cheese (Rouelle.)

2°. *Fibrin.*—When lean beef or mutton is long washed in water till it becomes colourless, and is then boiled in alcohol to separate the fat, a colourless, elastic, fibrous mass is obtained, which is the fibrin of chemists. In recently drawn blood it exists in the liquid state, but coagulates spontaneously when exposed to the air, and forms the greater part of the *clot* of blood. It dissolves in a solution of caustic potash or of nitre, and in vinegar.

3°. *Albumen.*—This substance in the liquid state exists in the white a quarter of an hour, is then poured off, filtered, evaporated to a small bulk over boiling water, again filtered if necessary, and then mixed with much alcohol, a white tasteless powder falls—to which the name of *diastase* has been given.

of egg, and in the serum of the blood. It coagulates by heating to 160° F., or if previously mixed with water by raising to 212° F.

These three substances, in addition to their well known sensible properties, are distinguished as follows:

1°. *Liquid casein* in milk, is not coagulated by heating *alone*—the addition of rennet or of a little acid (vinegar or spirit of salt) is necessary, when it curdles readily.

2°. *Liquid albumen* in white of egg, coagulates by heat alone, as when an egg is put into hot water.

3°. *Liquid fibrin* in the blood coagulates by mere exposure to the air, or more rapidly by agitation in contact with the air.

Like starch and sugar these three substances are mutually convertible by known means. Thus *fibrin*, if unboiled, dissolves by digestion at 80° F. in a saturated solution of nitre, and acquires the properties of *liquid albumen;* and if to *liquid albumen* a little caustic potash be added, and afterwards much alcohol, it will be thrown down in the form and with the properties of *casein.*

All these substances appear to contain the same organic constituents in the same proportions.

Boussingault first shewed the identity in chemical constitution of gluten and vegetable albumen.* Mulder afterwards proved a similar identity between vegetable albumen and the white of egg, fibrin, and casein.† Mulder supposes them to differ from each other by the presence in unlike quantities of a small admixture of sulphur, phosphorus or phosphate of lime.

Those who are not familiar with the history and with the nature of chemical research, can form no idea of the time and labour which has by different chemists been expended on this one branch. The persevering industry of Dr. Mulder, of Rotterdam, appeared to have cleared up the entire subject by a long series of investigations and analyses,‡ when first Vogel, then Prosper Denis, and latest Liebig and Dr. Scheerer, have arrived at different results. Our ideas are thus again unfixed, and our partial generalizations set aside for future emendation.

The analysis inserted in the text, as representing the composition of gluten and vegetable albumen, is that given by Dr. Scheerer for the purest form of *fibrin.* I have selected it in preference to the results either of Boussingault or of Mulder, because it is the most recent, and has been obtained with a knowledge of all the previous researches,—and assuming the chemical identity of this entire group of substances, is the

[* Pog. An. xl. p. 253.]

[† Ann. de Chim. et de Phys. lxv. p. 301.]

[‡ For an outline of his results, see Berzelius Årsberättlese, 1839, p. 611.]

If unmalted barley be so treated no diastase is obtained. This substance, therefore, *is formed during the process of malting.*

If wheat, or barley, or potatoes, which by steeping in water yield no diastase, be made to germinate (or sprout), and be afterwards bruised and treated as above, diastase will be obtained. *It is therefore produced during germination.*

If the shoot of a potatoe be cut off within half an inch of its base, this lower portion with the part of the potatoe to which it is immediately attached, separated from the rest—and the three parts (the upper portion of the shoot—the lower portion with its attached fragment of potatoe—and the remaining mass of the potatoe) treated with water,—only that portion will yield diastase in which the base of the shoot is situated. When a seed sprouts, therefore, *this substance is formed at the base of the germ*, and there remains during its growth.

If the same portion of the potatoe, or if the grain of barley or wheat is examined, when the first true leaves of the plant have been fully formed and expanded, the diastase will be found to have in great part, if not entirely, disappeared. This substance, therefore, is first formed when the seed begins to sprout, performs a function which makes its presence necessary at the base of the germ, and which function being discharged when the true leaves are formed, it then disappears. What is the nature of this temporary function, why the diastase must reside at the base of the sprout in order to discharge it, and why it should so early cease, will appear from a detail of the properties of this singular substance.

Properties of diastase.—If the solution obtained from malt be digested with potatoe, flour, or other starch, at a temperature between 120° and 140° F., the latter will gra-

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most likely to represent their constitution with accuracy. It differs from the analysis of Mulder *only* in stating the nitrogen at 2 per cent. higher than was done by that chemist. The recent improvements in the mode of determining the true quantity of nitrogen in organic substances, appear to justify us in expecting the result of Scheerer to be in this respect the more correct.

dually dissolve and will form a colourless transparent solution. When this solution is carefully evaporated a yellowish white powder is obtained, perfectly soluble in water, to which the name of *dextrine*[*] has been given. This dextrine has the same composition as starch. It is merely starch changed or transformed in such a way as to become soluble in cold water,—a change analogous to that which it undergoes by simply boiling in water.

But if the digestion be continued after the starch is dissolved, the solution will gradually acquire a sweet taste, and if it be now evaporated it will yield, instead of dextrine, a mixture of gum and grape sugar. And if the digestion be still further prolonged, the whole of the starch will be converted into grape sugar only.[†]

Thus *diastase* (like sulphuric acid) possesses the property of transforming starch entirely—first into gum, and then into grape sugar. The intermediate stage of dextrine has not been recognised in the action of sulphuric acid, nor is it easy to arrest the action of diastase exactly at this point—the most carefully prepared dextrine always containing a mixture of gum and sugar. One part of diastase will convert into sugar 2000 parts of starch.

A solution of diastase, when allowed to stand, soon undergoes decomposition, and after being boiled, it has no further effect upon starch. It has not been analysed, because it is difficult to obtain it in a pure state. It contains nitrogen, however, for, when moistened and exposed to the air, it decomposes, and, among other products, yields ammonia.[‡]

The functions of diastase—one of the purposes at least for which it is produced in the living seed, and situated at the base of the germ—will now be in some measure understood. The starch in the seed is the food of the future germ, prepared and ready to minister to its wants whenever heat and moisture concur in awakening it to life. But starch is itself insoluble in water, and could not, therefore, accompany the fluid sap when it begins to move and circulate. For this reason diastase is formed at the point where the germ first issues from the mass of food. There it transforms the starch, and renders it soluble, so that the young vessels can take it up and convey it to the point of growth. When the starch is exhausted its functions cease. It is then itself transformed and carried into the general circulation. Or when, as in the potatoe, much more starch is present than is in many cases requisite, its function ceases long before the whole of the starch disappears. Its presence is necessary only until the leaves and roots are fully formed—when the plant is enabled to provide for itself, and becomes independent of the starch of the seed. When this period arrives, therefore, the production of diastase is no longer perceived.

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[*] Because its solution turns to the *right* a ray of polarized light when passed through it.

[†] See above § 6, p. 166.

[‡] It will be recollected that ammonia contains nitrogen, being represented by NH^3. See Lecture III., p. 68.

This I have said is one of the purposes which appears to be served by diastase in the vegetable economy. That it is the only one we have no reason to believe. There may be others quite as interesting which we do not as yet understand. This is rendered more probable by the fact that the diastase contained in one pound of malted barley is capable of converting into sugar five pounds* of starch. (Liebig.) And though at the temperature at which the seed germinates, more of this substance may be necessary to transform the same weight of starch than is required in our hands, when aided by artificial heat,—yet as we never in the ordinary course of nature find any thing superfluous or going to waste, there is reason to believe that the diastase may be intended also to contribute directly to the nourishment and growth of the plant. As it contains nitrogen, it must be derived from the gluten or vegetable albumen of the seed; and as a young plant of wheat, when already many inches from the ground, contains no more nitrogen than was originally present in the seed itself (Boussingault), this diastase may only be the result of one of those transformations of which gluten* is susceptible, and by which it is rendered soluble, and capable of aiding in the production of those parts of the substance of the growing plant into which nitrogen enters as a necessary constituent.

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* It is the diastase in malt which dissolves the starch of the barley in the process of brewing, but as the diastase contained in malt is sufficient to dissolve so large a quantity of starch, it is obviously a waste of labour to malt the whole of the barley employed. One of malt to three of barley would probably be sufficient in most cases to obtain a wort containing the whole of the starch in solution. Advantage is taken of this property in the manufacture of the *white beer* of Louvain, and of other places in Flanders, and in Germany, where the light colour is secured by adding a large quantity of flour to a decoction of a small quantity of barley.

It may not be uninstructive if we pause here for a moment and consider the beauty of the arrangements we have just been describing. In passing through a new and interesting country we do not hesitate, at times, to stop and gaze, and leisurely admire. We cannot otherwise fully realize and appreciate its beauty. So in the domains of science, we cannot be ever hurrying on—we must linger occasionally, not only that we may more carefully observe, but that we may meditate and feel.

You see how bountifully nature has provided in the seed for the nourishment of the young plant, how carefully the food is stored up for it, and in how imperishable a form—how safely covered also and protected from causes of decay! For hundreds of years the principle of life will lie dormant, and for as many the food will remain sound and undiminished till the time of awakening comes. Though buried deep in the earth, the seed defies the exertions of cold or rain, for the food it contains is unaffected by cold and absolutely insoluble in water. But no sooner is the sleeping germ recalled to life, by the access of air and warmth and duly tempered moisture, than a new agent is summoned to its aid, and the food is so changed as to be rendered capable of ministering to its early wants. The first movement of the nascent germ—(and how it moves, by what inherent or impartial force, who shall discover to us?)—is the signal for the appearance of this agent—diastase—of which, previous to germination, no trace could be discovered in the seed. At the root of the germ, where the vessels terminate in the farinaceous matter, exactly where it is wanted, this substance is to be found;—there, and there only, resolving and transforming the otherwise unavailable store of food, and preparing it for being conveyed either to the ascending sprout or to the descending root. And when the necessity for its presence ceases—when the green leaf becomes developed, and the root has fairly entered the soil—when the plant is fitted to seek food for itself—then this diastase disappears, it undergoes itself a new conversion, and is prepared in another form to contribute to the further increase of the plant.

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* That *diastase* is merely *transformed* gluten we cannot say, because the exact chemical constitution of diastase is as yet unkuown.

How beautiful and provident are all these arrangements!—how plastic the various forms of organic matter in the hands of the All-Intelligent!—how nicely adjusted in time and place its diversified changes! What an apparently lavish expenditure of forethought and kind prevision, in behalf even of the meanest plant that grows!

§ 9. *Vegetable acids.—Acetic acid, Oxalic acid, Tartaric acid, Citric acid, Malic acid.*

Another class of compound substances remains to be shortly considered,—those, namely, which possess sour or acid properties, and which are known to be present in large quantity in many plants, and more especially in the greater number of unripe fruits. They do not, taken as a whole, form any large portion of the entire produce, either of the general vegetation of the globe or of those plants which are cultivated for food; yet the growth of fruit—as in the grape, orange, and apple countries—is sufficiently extensive, and the general interest in the cultivation of fruit trees sufficiently great, to require that the nature of the substances contained in fruits, and the peculiar changes by which they are formed, should be in some measure considered and explained.

I.—ACETIC ACID.

Acetic acid or vinegar is the most extensively diffused, and the most largely produced, of all the organic acids. It is formed during the germination of seeds, and it exists in the juices of many plants, but it is most abundantly evolved during the fermentation, whether natural or artificial, of nearly all vegetable substances. When pure it is a colourless liquid, having a well known agreeably acid taste. It may be boiled and distilled over without being decomposed. The vinegar of the shops is generally very much diluted, but it can be prepared of such a strength as to freeze and become solid at 45° F., and to blister the skin and produce a sore when applied to any part of the body. When mixed with water it readily dissolves lime, magnesia, alumina, &c., forming *salts* called *acetates*, which are all soluble in water, and may, therefore, be readily washed out of the soil or of compost heaps by heavy falls of rain.

When perfectly free from water, acetic acid consists of—

Carbon	47·5 per cent.,	or 4 atoms.
Hydrogen	5·8 per cent.,	or 3 atoms.
Oxygen	46·7 per cent.,	or 3 atoms.
	100	

It is therefore represented by the formula $C^4 H^3 O^3$— in which, as in those given in the preceding sections for starch, sugar, &c., the numbers representing the atoms of hydrogen and oxygen are equal, and consequently these elements are in the proportion to form water. Hence, vinegar, like sugar, may be represented by carbon and water.

Let us consider for a moment the several processes by which this acid is usually formed.

1°. *By the distillation of wood.*—This a method by which wood vinegar—often called *pyroligneous acid*—is prepared in large quantity. Wood which has been dried in the air is put into an iron retort and distilled. The principal products are vinegar, water, and tarry matter. The decomposition is of a complicated description, but by comparing the constitution of woody fibre with that of vinegar, we can readily see the nature of the changes by which the latter is produced.

Woody Fibre is = $C^{12} H^8 O^8$
3 of Vinegar are = $C^{12} H^9 O^9$

Difference = $H^1 O^1$; or the elements of one atom of water. One portion of the woody fibre, therefore, combines with the elements of an atom of water, obtained by the decomposition of another portion, and thus vinegar is produced.

2°. *Manufacture of Vinegar from Cane Sugar.*—It is a well known fact in domestic economy, that if cane sugar be dissolved in water, a little vinegar added to it, and the solution kept for a length of time at a moderate temperature, the whole will be converted into vinegar without any sensible fermentation. This process is frequently followed in the preparation of household vinegar, and was formerly adopted to some extent in our chemical manufactories. It will be recollected that we represented

$$\begin{array}{lll} \text{Cane Sugar by} & C^{12}\,H^{10}\,O^{10}, & \text{while} \\ \text{3 of Vinegar} = & C^{12}\,H^{9}\,O^{9} & \\ \hline \text{Difference} & H^{1}\,O^{1}; & \end{array}$$

or the elements of an atom of water, which cane sugar must *lose* in order to be converted into vinegar. Whether the change in this instance takes place by the direct conversion of cane sugar into vinegar, or whether the former is previously transformed into grape sugar, has not been satisfactorily determined.

3°. *Manufacture of Vinegar from Alcohol.*—In Germany, where common brandy is cheaper than vinegar, it is found profitable to manufacture this acid from weak spirit. For this purpose it is mixed with a little yeast, and then allowed to trickle over wood shavings moistened with vinegar, and contained in a cask, the sides of which are perforated with holes for the admission of a current of air. By this method oxygen is absorbed from the air, and in 24 hours the alcohol in the spirit is converted into vinegar and water.

The explanation of this process is also simple, alcohol being represented by $C^4\,H^6\,O^2$. Thus—

$$\left.\begin{array}{ll} \text{Alcohol} = & C^4\,H^6\,O^2 \\ \text{4 of Oxygen} = & O^4 \\ \hline \text{Sum} & C^4\,H^6\,O^6 \end{array}\right\} = \left\{\begin{array}{ll} \text{Vinegar} = & C^4H^3O^3 \\ \text{3 of Water} = & H^3O^3 \\ \hline \text{Sum} = & C^4H^6O^6 \end{array}\right.$$

4°. *Production of Vinegar by fermentation.*—When vegetable matters are allowed to ferment, carbonic acid is given off and vinegar is formed. In such cases this acid is the result of a series of changes, during which that portion of the vegetable matter which has at length reached the state of vinegar has most probably passed through the several previous stages of grape, sugar, and alcohol. The carbonic acid, as has already been explained (p. 169), is given off during the fermentation of the grape sugar, and the consequent formation of alcohol.

To simple transformations, similar to those above described, we can trace the origin of the vinegar which is met with in the living juices of plants, and among the products of their decay.

II.—TARTARIC ACID.

The grape and the tamarind owe their sourness to a peculiar acid to which the name of *tartaric acid* has been given. It is also present, along with other acids, in the mulberry, in the berries of the sumach (*rhus coriarii*), and in the sorrels, and has been extracted from the roots of the couch-grass and the dandelion.

When new wine is decanted from the lees, and set aside in vats or casks, it gradually deposits a hard crust or *tartar* on the sides of the vessels. This substance is known in commerce by the name of argol, and when purified is familiar to you as the cream of tartar of the shops. It is a compound of tartaric acid with potash, and from it tartaric acid is extracted for use in medicine and in the arts. The principal use of the acid is in certain processes of the calico printers.

The pure acid is sold either in the form of a white powder or of transparent crystals, which are colourless, and have an agreeable acid taste. It dissolves readily in water, and causes a violent effervescence when mixed with a solution of the carbonate of potash or of soda. As it has no injurious action upon the system, it is extensively used in artificial soda powders and effervescing draughts. When added in sufficient quantity to a solution containing potash, it causes a white crystalline powder to fall, which is cream of tartar (or *bitartrate of potash*), and from lime water it throws down a white chalky precipitate of *tartrate of lime*. Both of these compounds are present in the grape.

When perfectly free from water this acid consists of—

Carbon . . = 36·81 or 4 atoms.
Hydrogen . . = 3·00 or 2 atoms.
Oxygen . . = 60·19 or 5 atoms.
100

It is, therefore, represented by the formula $C^4 H^2 O^5$.

If we compare the numbers by which the atoms of hydrogen and oxygen in this acid are expressed, we see that these elements are not in the proportion to form water, and that this substance, therefore, cannot, like so many of those we have hitherto had occasion to notice, be represented by carbon and the elements of water *alone*.

It may be represented by

$$\left.\begin{array}{lcl} \text{4 of CARBON . .} & = & C^4 \\ \text{2 of WATER . .} & = & \quad H^2\,O^2 \\ \text{and 3 of OXYGEN . .} & = & \qquad O^3 \end{array}\right\} \text{or, } 4C + 2HO + 3O$$

$$\text{TARTARIC ACID} = C^4\,H^2\,O^5$$

And, though this mode of representation does not truly exhibit the constitution of the acid, inasmuch as we have no reason to believe that it really contains water as such—yet it serves to show very clearly that in the living plant this acid cannot be formed *directly* from carbon and the elements of water, as starch and sugar may, but that it requires also *three atoms of oxygen in excess* to every five of carbon and two of water. We shall, in the following lecture, see how nicely the functions of the several parts of the plant are adjusted,—at one period to the formation of this acid, and at another to its conversion into sugar during the ripening of the fruit.

III.—CITRIC ACID, OR ACID OF LEMONS.

This acid gives their sourness to the lemon, the lime, the orange, the cranberry, the red whortleberry, the bird-cherry, and the fruits of the dog-rose and the woody night-shade.

It is also found in some roots, as in those of the dahlia pinnata, and the asarum europæum (*asarrabacca*), and mixed with much malic acid, in the currant, cherry, gooseberry, raspberry, strawberry, common whortleberry, and the fruit of the hawthorn.

When extracted from the juice of the lemon or lime, and afterwards purified, it forms transparent colourless crystals, possessed of an agreeable acid taste; effervesces like tartaric acid with carbonate of soda, and like it, therefore, is much employed for effervescing draughts. With potash it forms a soluble salt, which is a *citrate of potash*, and from lime water it throws down a white, nearly insoluble, sediment of *citrate of lime*, which re-dissolves when the acid is added in excess. In combination with lime it exists in the tubers, and with potash in the roots, of the Jerusalem artichoke.

When free from water, citric acid consists of

Carbon . .	41·49	= 4 atoms.
Hydrogen . .	3·43	= 2 atoms.
Oxygen . . .	55·08	= 4 atoms.
	100	

and is therefore represented by $C^4 H^2 O^4$.

This formula differs from that assigned to the tartaric acid only in containing one atom of oxygen less, O^4 instead of O^5. In the citric acid, therefore, there are 2 atoms of oxygen in excess, above what is necessary to form water with the 2 of hydrogen it contains.

IV.—MALIC ACID.

The malic and oxalic acids are more extensively diffused in *living* plants than any other vegetable acids. If acetic acid be more largely formed in nature, it is chiefly as a product of the decomposition of organic matter, when it has already ceased to exist in, or to form part of, a living plant.

Along with the citric acid, it has been already stated that the malic occurs in many fruits. It is found more abundantly, however, and is the chief cause of the sour taste, in the unripe apple,* the plum, the sloe, the elderberry, the barberry, the fruit of the mountain ash, and many others. It is associated with the tartaric acid in the grape and in the Agave americana.

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* Hence its name *malic* acid.

This acid is not used in the arts or in medicine, and therefore is not usually sold in the shops. It is obtained most readily, in a pure state, from the berries of the mountain ash. It forms colourless crystals, which have an agreeable acid taste. It combines with potash, soda, lime, and magnesia, and forms *malates*, and, in combination with one or more of these bases, it usually occurs in the fruits and juices of plants. The *malate* of lime is soluble, while the citrate, as already stated, is nearly insoluble, in water. This malate exists in large quantity in the juice of the house-leek (*sempervivum tectorum*) in the Sedum telephium, the Arum maculatum, and many other juicy and fleshy-leaved plants.

When perfectly free from water, the malic acid has exactly the same chemical constitution as the citric, and is represented by the same formula $C^4\ H^2\ O^4$. These two acids, therefore, bear the same relation to each other as we have seen that starch, gum, and sugar do. They are what chemists call *isomeric*, or are *isomeric* bodies. We cannot transform them, however, the one into the other, by any known means, though there is every reason to believe that they may undergo such transformations in the interior of living plants. Hence probably one reason also why the malic and citric acids occur associated together in so many different fruits.

V.—OXALIC ACID.

This acid has already been treated of, and its properties and composition detailed, in a preceding lecture (Lecture III. p. 61). It forms colourless transparent crystals, having an agreeably acid taste, and it effervesces with the carbonates of potash and soda, but on account of its poisonous qualities, it is unsafe to administer it as a medicine. It occurs in combination with potash in the sorrels, in rhubarb, and in the juices of many lichens. Those lichens which incrust the sides of rocks and trees, not unfrequently contain half their weight of this acid in combination with lime. It can be formed artificially by the action of nitric acid on starch, sugar, gum, and many other organic substances.

When perfectly free from water, oxalic acid contains no hydrogen; but consists of—

Carbon	33·75	= 2 atoms.
Oxygen	66·25	= 3 atoms.
	100	

and it is represented by $C^2 O^3$. When heated with strong sulphuric acid, it is decomposed and resolved into gaseous carbonic acid ($C O^2$) and carbonic oxide ($C O$) in equal volumes. This change is easily understood since $C O^2 + C O = C^2 O^3$.

§ 10. *General observations on the substances of which plants chiefly consist.*

It may be useful here shortly to review the most important facts and conclusions which have been adverted to in the present lecture.

1°. The great bulk of plants consists of a series of substances capable of being represented by and consequently of being formed in nature from, carbon and the elements of water only. Such are woody fibre, starch, gum, and the several varieties of sugar (p. 162).

2°. Yet the crude mass of wood, as it exists in a full-grown tree, containing various substances in its pores, cannot be represented by carbon and the elements of water *alone*. It appears always to contain a small excess of hydrogen, which is greater in some trees than in others. Thus in the chesnut and the lime, this excess is greater than in the pines, while in the latter it is greater than in the oak and the ash.*

3°. These substances are, in many cases, mutually convertible even in our hands. They are probably, therefore, still more so in nature.

It is to be observed, however, that all the transformations we can as yet effect are in one direction only. We can produce the above compounds from each other in the order of lignin or starch, gum, cane sugar, grape sugar—that is, we can convert starch into gum, and gum into sugar, but we cannot reverse the process, so as to form cane from grape sugar, or starch from gum.

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* For a series of analyses of different kinds of wood by Petersen and Schödler, see Thomson's *Organic Chemistry*, p. 849.

The only apparent exception to this statement with which we are at present acquainted, occurs in the case of starch. When this substance is dissolved in *cold* concentrated nitric acid, and then mixed largely with water, a substance* falls to the bottom which is a compound of the nitric acid with woody fibre ($C^{12} H^{8} O^{8}$).† In this instance, if the above observation is correct, there appears to be an actual conversion of starch into woody fibre.

But what *we* are as yet unable to perform may, nevertheless, be easily and constantly effected in the living plant. Not only may what is starch in one part of the tree be transformed and conveyed to another part in the form of sugar,—but that which, in the form of sugar or gum, passes upwards or downwards with the circulating sap, may, by the instrumentality of the vital processes, be deposited in the stem in the form of wood, or in the ear in that of starch. Indeed we know that such actually does take place, and that we are still, therefore, very far from being able to imitate nature in her power of transforming even this one group of substances only.

4°. Among, or in connection with, the great masses of vegetable matter which consist mainly of the above substances, we have had occasion to notice a few which contain nitrogen as one of their constituents—and which, though forming only a small fraction of the products of vegetable growth, yet appear to exercise a most important influence in the general economy of animal as well of vegetable life. The functions performed by diastase in reference to vegetable growth, and to the transformations of organized vegetable substances, have already been in some measure illustrated,—we shall hereafter have an opportunity of considering more fully the influence which gluten and vegetable albumen exercise over the general efficiency of the products of vegetation in the support of animal life, and over the changes which these products must undergo, before they can be converted into the substance of animal bodies. In a former lecture (Lecture IV. p. 91), I have had occasion to draw your attention to the comparatively small proportion in which nitrogen exists in the vegetable kingdom, and to show that it must nevertheless be considered as much a necessary and constituent element in their composition as the carbon itself; the very remarkable properties we have already discovered in the compounds above mentioned strongly confirm this fact, and illustrate in a striking manner the influence of apparently feeble and inadequate causes in producing important natural results.

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* The *Xyloidin* of Braconnot.

† Pelouze, see Berzelius *Arsberättelse*, 1839, p. 416.

5°. With the exception of acetic acid, which in constitution is closely related to sugar* and gum, all the acid substances to which it has been necessary to advert, contains an excess of oxygen above what is necessary to form water with the hydrogen they contain. Thus

Vinegar = $C^4 H^3 O^3$ contains no excess of oxygen.
Tartaric Acid = $C^4 H^2 O^5$ . . . 3 of oxygen in excess.
Malic Acid }
Citric Acid } = $C^4 H^2 O^4$ . . . 2 . . . . . .
Oxalic Acid = $C^2 O^3$ . . . 3 . . . . . .

It requires a little consideration to enable us to appreciate the true importance of these and other organic acids, in the vegetable economy. At first sight they appear to form a much smaller part of the general products of vegetation than is really the case. We must endeavour to conceive the quantity actually produced by a single tree loaded with thousands of lemons, oranges, or apples,—or again how much is formed during the growth of a single comparatively

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* It is identical in constitution with *caramel* (p. 167)—the uncrystallizable sugar of syrups. For

$$\overset{\text{Vinegar.}}{(C^4 H^3 O^3} \times 3) = \overset{\text{Caramel.}}{C^{12} H^9 O^9}.$$

small plant of garden rhubarb in spring, if we would obtain an adequate idea of the extent to which these acids are constantly formed in nature. On the other hand, we must recollect also that the greater portion of the acid of fruits disappears as they ripen, if we would understand the true nature of the interest which really attaches to the study of these substances, of the changes to which they are liable, and of the circumstances under which in nature these changes take place.

6°. I will venture here to draw your attention for a moment to the nature and extent of that remarkable power over matter, which the chemist, as above explained, appears to possess. Such a consideration will be of value not only in illustrating how far we really can now, or may hereafter, expect to be able to influence or control natural operations,* but what is probably of more value still, in exhibiting the true relation which man bears to the other parts of creation; and, therefore, in some measure, the true position he is intended to occupy among them.

1°. We have seen that the chemist can *transform* certain substances one into the other, in a known order; but that as yet he cannot reverse that order. Thus far his power over matter is at present limited; but this limit he may at some future period be able to overpass, and we know not how far. The discovery of a new agent, or of a new mode of treatment, may enable him to accomplish what he has not as yet the means or the skill to perform.

2°. He has it in his power to form, actually to produce, some of the organic or organized substances which occur in living plants. He can form gum, and grape sugar, in any quantity. *Thus far he can imitate and take the place of the living principle itself.*

Numerous other cases are known, in which he displays a similar power. By the action of nitric acid upon starch† or sugar, he can form *oxalic acid*, which, as has already been shewn, occurs very largely in the vegetable kingdom. By the action of heat upon citric acid, he can decompose it and produce an acid which is met with in the Wolfsbane (Aconitum napellus), and hence is called *aconitic acid.** Also by the action of sulphuric acid he can change *salicine* and *phlorizine*—substances extracted respectively from the bark of the willow and from that of the root of the apple tree—into a resinous matter and *grape sugar*. So, of the compounds which are found in the solids and fluids of animal bodies, there are some, which he has also succeeded in forming by the aid of his chemical art.

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* See Lecture II., p. 37.

† See Lecture III., p. 61.

Elated by such achievements, some chemists appear willing to hope that all nature is to be subjected to their dominion, and that they may hereafter be able to rival the living principle in all its operations. It is true that what we now know, and can accomplish, are but the beginnings of what we may fairly expect hereafter to effect. But it is of consequence to bear in mind the true position in which we now stand, and the true direction in which all we at present know seems to indicate that our future advances in knowledge, and in control over nature, are likely to proceed. And this leads me to observe—

3°. That our dominion is at present limited solely to transforming and decomposing. We can *transform* woody fibre into gum or sugar—*we cannot form either gum or sugar by the direct union of their elements*. We can *resolve* salicine by the acid of sulphuric acid into resin and grape sugar; but we cannot cause the elements of which they consist to unite together in our hands, so as to form any one of the three. We cannot even cause the resin and the sugar to re-unite and rebuild the salicine from which they were derived.

So we can by heat drive off the elements of water from

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* These two acids differ from each other only by the elements of an atom of water. Thus

$$\begin{array}{lll} \text{Citric Acid} \;.\;.\;.\; = & C^4\ H^2\ O^4 & \\ \text{Aconitic Acid} \;.\;.\; = & C^4\ H^1\ O^3 & \\ \hline \text{Difference} \;.\;.\;.\;.\; = & \quad H^1\ O^1 & \text{or HO, one of water.} \end{array}$$

It is easy to see, therefore, how, by the evolution of the elements of an atom of water, the one acid may be changed into the other. The scientific reader will excuse me (if on the grounds of simplicity alone) for representing, both here and in the text, the citric acid by $C^4\ H^2\ O^4$ instead of by $C^{12}\ H^5\ O^{11} + 3\,HO$, which Liebig and his pupils prefer.

the citric and cause the aconitic acid to appear; but we cannot persuade the unwilling compounds, when thus separated, to return to their former condition of citric acid; and, if we could, we should still be as far removed from the power of commanding or compelling the direct union of carbon, hydrogen, and oxygen, in such proportions, and in such a way, as to build up either of the two acids in question.

Again, we can actually form oxalic acid by the action of nitric acid upon starch, or wood, or sugar, or any other of a great variety of vegetable substances—but we cannot prepare it by the direct union of its elements. We can only as yet procure it from substances which have already been *organized*—which have been themselves produced by the agency of the living principle.

The same remarks apply with slight alteration to those substances of animal origin, to which I have above alluded as being within the power of the chemist to produce at will. There is hardly an exception to the rule, that in producing *organic* substances, as they are called, the chemist must employ other organic substances which are as yet beyond his art—which, so far as we know, can only be formed under the direction of the living principle. Thus the sum of the chemist's power in imitating organic nature consists, at present, in his ability—

1°. To *transform* one substance found only in the organic kingdom into some other substances, produced more or less abundantly in the same kingdom of nature. This power he exercises when he converts starch into sugar, or fibrin into albumen or casein.

2°. To *resolve* a more complex or compound substance into two or more which are less so, and of which less complex substances some may be known to occur in vegetable or animal bodies.

3°. To decompose organic compounds by means of his chemical agents, and as the result of such decompositions to arrive at one or more compounds, such as are formed under the direction of the living principle.

In no one case can he form the substances of which animals and plants chiefly consist, out of those on which animals and plants chiefly live.

But this is the common and every-day result of the agency of the living principle. Is there as yet, then, any hope that the chemical laboratory shall supersede the vascular system of animals and plants; or that the skill of the chemist who guides the operations within it, shall ever rival that of the principle of life which presides over the chemical changes that take place in animal and vegetable bodies?

The true place, therefore, of human skill—the true prospects of chemical science—are pointed out by these considerations. No science has accumulated so many and such various treasures as chemistry has done during the last 20 years—none is at present so widely extending the bounds of our knowledge at this moment as the branch of organic chemistry—men may therefore be excused for entertaining more sanguine expectations from the progress of a favourite science than sober reasoning would warrant. Yet it is of importance, I think, and especially in a moral point of view, that amid all our ardor, we should entertain clear and just notions of the kind and extent of knowledge to which we are likely to attain, and—as knowledge in chemistry is really power over matter—to what extent this power is likely ever to be carried.

At present, if we judge from our actual knowledge, and not from our hopes—there is no prospect of our ever being able to imitate or rival living nature in actually compounding from their elements her numerous and varied productions. That we may clearly understand, and be able to explain many of her operations, and even to aid her in effecting them, is no way inconsistent with an inability to imitate her by the resources of art. This will, I trust, appear more distinctly in the subsequent lecture.

LECTURE VII.

Chemical changes by which the substances of which plants chiefly consist are formed from those on which they live. Changes during germination—during the growth of the plant—during the ripening of fruit. Autumnal changes.

Having thus considered the nature and chemical constitution of those substances which constitute by far the largest part of the solids and fluids of living vegetables, we are now prepared for the further question—*by what chemical changes these substances of which plants consist, are formed out of those on which they live.*

The growth of a plant, from the germination of the seed in spring till the fall of the leaf in autumn, or the return of the succeeding spring time, may in perennial plants be divided into four periods—during which they either live on different food, or expend their *main* strength in the production of different substances. These periods may be distinguished as follows:—

1°. The period of germination—from the sprouting of the seed to the formation of the perfect leaf and root.

2°. From the expansion of the first true leaves to the period of flowering.

3°. From the opening of the flower to the ripening of the fruit and seed.

4°. From the ripening of the seed or fruit, till the fall of the leaf and the subsequent return of spring. On the ripening of the fruit the functions of annual plants are in general discharged, and they die; but perennial plants have still important duties to perform in order to prepare them for the growth of the following spring.

The explanation of the chemical changes to which our attention is to be directed will be more clear, and perhaps more simple, if we consider them in relation to these several periods of growth.

§ 1. *Chemical changes which take place during germination and during the development of the first leaves and roots.*

The general nature of the chemical changes which take place during germination is simple and easy to be comprehended.

Let us first consider shortly the phenomena which have been observed to accompany germination, and the circumstances which are most favourable to its rapid and healthy progress.

1°. Before a seed will begin to sprout, it must be placed for a time in a sufficiently moist situation. We have already seen how numerous and important are the functions which water performs in reference to vegetable life (Lecture II., p. 42,) in every stage of a plant's growth. In the seed no circulation can take place—no motion among the particles of matter—until water has been largely imbibed; nor can the food be conveyed through the growing vessels, unless a constant supply of fluid be afforded to the seed and its infant roots.

2°. A certain degree of warmth—a slight elevation of temperature—is also favourable, and in most cases necessary, to germination.

The degree of warmth which is required in order that seeds may begin to grow, varies with the nature of the seed itself. In Northern Siberia and other icy countries, plants are observed to spring up at a temperature but slightly raised above the freezing point (32° F.,) but it is familiar to every practical agriculturist, that the seeds he yearly consigns to the soil require to be protected from the inclemency of the weather, and sprout most quickly when they are stimulated by the warmth of approaching spring, or by the heat of a summer's sun.

The same fact is familiarly shown in the malting of barley, where large heaps of grain are moistened in a warm atmosphere. When germination commences, the grain heats spontaneously, and the growth increases in rapidity as the heap of corn attains a higher temperature. It thus appears that some portion of that heat which the growth of the germ and radicles requires, is provided by natural processes in the grain itself; in some such way as in the bodies of animals, a constant supply of heat is kept up by the vital processes—by which supply the cooling effect of the surrounding air is continually counteracted.

We have seen in the preceding lecture, that the transformations of which starch and gum are susceptible, take place with greater certainty and rapidity under the influence of an elevated temperature. It will presently appear that such transformations are also effected during germination; there is reason, therefore, to believe that the external warmth which is required in order that germination may begin, as well as the internal heat naturally developed as germination advances, are both employed in effecting these transformations. And, as the young sprout shoots more rapidly under the influence of a tropical sun, it is probable that those natural agencies in general, by which such chemical transformations are most rapidly promoted, are also those by which the progress of vegetation is in the greatest degree hastened and promoted.

3°. It has been observed that seeds refuse to germinate if they are entirely excluded from the air. Hence seeds which are buried beneath such a depth of soil that the atmospheric air cannot reach them, will remain long unchanged, evincing no signs of life—and yet, when turned up or brought near the surface, will speedily begin to sprout. Thus in trenching the land, or in digging deep ditches and drains, the farmer is often surprised to find the earth, thrown up from a depth of many feet, become covered with young plants, of species long extirpated from or but rarely seen in his cultivated fields.

4°. Yet light is, generally speaking, prejudicial to germination. Hence the necessity of *covering* the seed, when sown in our gardens and corn fields, and yet of not so far burying it that the air shall be excluded. In the usual method of sowing broad-cast, much of the grain, even after harrowing, remains uncovered; and the prejudicial influence of light in preventing the healthful germination of such seeds is no doubt one reason why, by the method of dibbling, fewer seeds are observed to fail, and an equal return of corn is obtained from a much smaller expenditure of seed.

The reason why light is prejudicial to germination, as well as why the presence of atmospheric air is necessary, will appear from the following observation :—

5°. When seeds are made to germinate in a limited portion of atmospheric air, the bulk of the air undergoes no material alteration, but on examination, its oxygen is found to have diminished, and carbonic acid to have taken its place. Therefore, *during germination, seeds absorb oxygen gas and give off carbonic acid.*

Hence it is easy to understand why the presence of air is necessary to germination, and why seeds refuse to sprout in hydrogen, nitrogen, or carbonic acid gases. *They cannot sprout unless oxygen be within their reach.*

We have seen also in a previous lecture that the leaves of plants in the sunshine give off oxygen gas and absorb carbonic acid,—while in the dark the reverse takes place. So it is with seeds which have begun to germinate. When exposed to the light they give off oxygen instead of carbonic acid, and thus the natural process is reversed. But it is necessary to the growth of the young germ, that oxygen should be absorbed, and carbonic acid given off—and as this can take place to the required extent only in the dark, the cause of the prejudicial action of light is sufficiently apparent, as well as the propriety of covering the seed with a thin layer of soil.

6°. During germination, vinegar (acetic acid) and diastase are produced. That such is the case in regard to the latter substance, has been proved in the previous lecture—(p. 174). That acetic acid is formed is shown by causing seeds to germinate in powdered chalk or carbonate of lime, when after a time *acetate of lime** may be washed out from the chalk (Braconnot) in which they have been made to grow. The acid contained in this acetate must have been formed in the seed, and afterwards excreted or thrown out into the soil.

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* *Acetate of lime* is a compound of acetic acid (vinegar) and lime, and may be prepared by dissolving chalk in vinegar. It is very soluble in water.

7°. When the germ has shot out from the seed and attained to a sensible length, it is found to be possessed of a sweet taste. This taste is owing to the presence of *grape* sugar in the sap which has already begun to circulate through its vessels.

It has not been clearly ascertained whether the vinegar or the diastase is first produced when germination commences, but there seems little doubt that the grape sugar is formed subsequently to the appearance of both.

8°. The young shoot which rises upwards from the seed consists of a mass of vessels, which gradually increase in length, and after a short time expand into the first true leaves. The vessels of this first shoot do not consist of unmixed woody fibre. It is even said that *no true wood is formed till the first true leaves are developed.*[*] The vessels of the young sprout, therefore, and of the early radicles, probably consist of the *cellular fibre* of Payen. They are unquestionably formed of a substance which is in a state of transition between starch or sugar and woody fibre, and which has a constitution analogous[†] to that of both.

Having thus glanced at the phenomena which attend upon germination, let us now consider the chemical changes by which these phenomena are accompanied.

1°. The seed absorbs oxygen and gives off carbonic acid. We have already seen that the starch of the seed ($C^{12} H^{10} O^{10}$) may be represented by carbon and water,—by $12C + 10 HO$. Now it appears that in contact with the oxygen of the atmosphere, a portion of the starch is actually separated into carbon and water, the carbon at the moment of separation uniting with the oxygen, and forming carbonic acid (CO^2). This acid is given off into the soil in the form of gas, and thence partially escapes into the air; but for what *immediate* purpose it is evolved, or how its formation is connected with the further development of the germ, has not hitherto been explained.

2°. The formation of acetic acid (vinegar) from the starch of the grain is also easy to comprehend. For as we have already seen

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[*] Lindley's *Theory of Horticulture.*

[†] By *analogous* I mean which may be represented by carbon and water.

STARCH	. . . =	$C^{12} H^{10} O^{10}$
3 of VINEGAR	. . =	$C^{12} H^{9} O^{9}$
Difference	. . =	$H^{1} O^{1}$;

or the elements of an atom of water. Therefore, in this early stage of the growth of the germ a portion of the starch is deprived of the elements of an atom of water, and at the same time transformed into vinegar.

Why is this vinegar formed? It is almost as difficult to answer this question as to say why carbonic acid is evolved from the seed, though both undoubtedly serve wise and useful ends.

It has been explained in the preceding lecture how the action of dilute acids gradually changes starch into cane sugar, and the latter into grape sugar. While it remains in the sap of the sprouting seed, the vinegar may aid the diastase in transforming the insoluble starch into soluble food for the plant, and may be an instrument in securing the conversion of the *cane* sugar, which is the first formed, into *grape* sugar,—since cane sugar cannot long exist in the presence of an acid.

After the acetic acid is rejected by the plant, it may act as a solvent on the lime and other earthy matters contained in the soil. Liebig supposes the especial function of this acid—the reason why it is formed in the germ and excreted into the soil—to be, to dissolve the lime, &c., which the soil contains, and to return into the pores of the roots, bearing in solution the earthy substances which the plant requires for its healthy growth. This is by no means an unlikely function. It is only conjectural, however, and since the experiments of Braconnot have shown that *acetate of lime*, even in small quantity, may be injurious to vegetation, it becomes more doubtful how far the formation of this compound in the soil, and the subsequent conveyance of it into the circulation of the plant, can be regarded as the special purpose for which acetic acid is so generally produced during germination.

3°. The early sap of the young shoot is sweet; it contains grape sugar. This sugar is also derived from the starch of the seed. Being rendered soluble by the diastase formed at the base of the germ, the starch is gradually converted into grape sugar as it ascends. The relation between these two compounds has been already pointed out.

Starch . . . = $C^{12} H^{10} O^{10}$
Grape Sugar . = $C^{12} H^{12} O^{12}$

Difference . = $H^{2} O^{2}$; or the elements of two atoms of water. The water which is imbibed by the seed from the soil, forms an abundant source from which the whole of the starch, rendered soluble by the diastase, can be supplied with the elements of the two atoms of water which are necessary to its subsequent conversion into grape sugar.

4°. The diastase is formed when the seed begins to sprout, at the expense of the gluten or vegetable albumen of the seed, but as its true constitution is not yet known, we cannot explain the exact chemical changes by which its production is effected.

5°. When the true leaf becomes expanded, true wood first appears in sensible quantity. By what action of the sun's rays upon the leaf the sugar already in solution in the sap is converted into woody fibre, we cannot explain. The conversion itself is *in appearance* simple enough, since

Grape Sugar . . = $C^{12} H^{12} O^{12}$, and
Woody Fibre . . = $C^{12} H^{8} O^{8}$

Difference . . = $H^{4} O^{4}$; or the former must part with the elements of four atoms of water only, to be prepared for its change into the latter. But the true nature of the *molecular** change by which this transformation is brought about, as well as the causes which lead to it and the immediate instruments by which it is effected, are all still mysterious.

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* All bodies are supposed to consist of particles or *molecules* of exceeding minuteness, and all chemical changes which take place in the same mass of matter are supposed to be owing to the different ways in which these particles arrange themselves. We may form a remote idea of the way in which different positions of the same particles may produce different substances, by considering how different figures in Mosaic may be produced by different arrangements of the same number of equal and similar fragments of various colours.

§ 2. *Of the chemical changes which take place from the formation of the true leaf to the expansion of the flower.*

When the true leaf is formed the plant has entered upon a new stage of its existence. Up to this time it is nourished almost solely by the food contained in the seed,—it henceforth derives its sustenance from the air and from the soil. The apparent mode of growth is the same, the stem shoots upwards, the roots descend, and they consist essentially of the same chemical substances, but they are no longer formed at the expense of the starch of the seed, and the chemical changes of which they are the result, are entirely different.

1°. The leaf absorbs carbonic acid in the sunshine, and gives off oxygen in equal bulk.* It is in the light of the sun that plants increase in size—their growth, therefore, is intimately connected with this absorption of carbonic acid.

If carbonic acid be absorbed by the leaf and the whole of its oxygen given off again,† carbon alone is added to the plant by this function of the leaf. But it is added in the presence of the water of the sap, and thus is enabled by uniting with it to form, as *it may be directed*, or as may be necessary, any one of those numerous compounds which may be represented by carbon and water, (p. 163,) and of which, as we have seen, the solid parts of plants are chiefly made up.

There are two ways in which we may suppose the oxygen given off by the leaf to be set free, and the starch, sugar, and gum, to be subsequently formed.

A. The action of light on the leaf of the plant may directly *decompose the carbonic acid* after it has been absorbed, and cause the oxygen to separate from the carbon, and escape into the air;—while at the same instant the carbon thus set free, may unite with the water of the sap in different proportions, so as to produce either sugar, gum, or starch. Suppose 12 atoms of carbonic acid ($12\,CO^2$) to be thus decomposed, and their carbon to unite with 10 of water ($10\,HO$), we should have

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* Such is *sensibly* the result of experiment. How far this result can be considered as universally true, will be examined hereafter.

† It will be recollected that carbonic acid contains its own bulk of oxygen gas: if, therefore, the leaf give off the same bulk of oxygen as it absorbs of carbonic acid, the result must be as stated in the text.

from 12 of Carbonic Acid . = C^{12} which united
to 10 of Water . . . = $H^{10}\,O^{10}$, would give

1 of Gum or of Cane Sugar = $C^{12}\,H^{10}\,O^{10}$

while 24 of oxygen would be given off, *the whole of which would have been derived from the carbonic acid* absorbed by the plant.

B. Or the action of the sun's rays may be directed, in the leaf, to the *decomposition, not of carbonic acid, but of the water* of the sap. The oxygen of the water may be separated from the hydrogen, while at the same instant the latter element (hydrogen) may unite with the carbonic acid to produce the sugar or starch. The result here is the same as before, but the mode in which it is brought about is very differently represented, and appears much more complicated. Thus, suppose 24 of water ($24\,HO$) to be decomposed, and to give off their oxygen into the air, 24 of oxygen would be evolved as in the former case, the whole of *which would be derived from the decomposition of water*, while there would remain

24 of Hydrogen . . = H^{24} Let this act on
12 of Carbonic Acid = C^{12} O^{24}, and we have

as the result . . . . . $C^{12}\,H^{24}\,O^{24}$; or

$$\underset{\text{Starch, \&c.}}{C^{12}\,H^{10}\,O^{10}} + \underset{\text{Water.}}{14\,HO}.$$

According to this mode of representing the chemical changes, water is first decomposed and its oxygen evolved, then its hydrogen again combines with the carbon and oxygen of the carbonic acid, forming two products—water and sugar or starch. This view is not only more complicated, but it supposes the same action of light to be—continually, at the same time, and in the same circumstances—both decomposing water and *re*-forming it from its elements. While, therefore, there can be no doubt, for other reasons not necessary to be stated in this place, that the light of the sun really does decompose water in the leaves of plants, and more in some than in others—yet it appears probable that the oxygen evolved by the leaf is derived in a great measure from the carbonic acid which is absorbed; and that the principal part of the solid substance of living vegetables, in so far at least as it is derived from the air, is produced by the union of the carbon of this acid with the elements of the water in the sap.*

2°. We have seen reason to conclude (p. 87) that, while plants derive much of their sustenance from the air, they are also fed more or less abundantly by the soil in which they grow. From this soil they obtain through their roots the carbonic acid which is continually given off by the de-

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* I ought not to pass unnoticed the opinion of Persoz (*Chemie Moleculaire*), that the starch, gum, &c., of plants are formed by the union of *carbonic oxide* (CO) with the necessary proportions of oxygen and hydrogen derived from the water of the sap. This opinion implies that, in the leaf, carbonic acid (CO^2) is decomposed into carbonic oxide and oxygen ($CO + O$), and that water likewise is decomposed,—the oxygen produced by both decompositions being given off either into the air by the leaves, or into the soil by the roots. The production of grape sugar, therefore, according to this hypothesis, would be thus represented:—

	There are retained,	and given off
From 12 of CARBONIC ACID = $12CO^2$ . .	C^{12} O^{12}	.... O^{12}
From 12 of WATER ...... = $12HO$ . .	H^{12}	.... O^{12}
	$C^{12}H^{12}O^{12}$	O^{24}
	$\underbrace{\text{grape sugar}}$	

Of the 24 of oxygen thus given off, the opinion of Persoz is, that only one-half is evolved by the leaf,—and the principal fact on which his opinion rests is that observed by de Saussure, that plants of *Vinca minor* gave off by their leaves, in his experiments, only two-thirds of the oxygen contained in the carbonic acid they absorbed. This result has led Berzelius also to conjecture that the leaves of plants do not retain merely the carbon of the carbonic acid, but some compound of carbon with oxygen, containing much less of this element than the carbonic acid does (*Traité de Chemie*, V. p. 69). The principal objection to this view, however, is the quantity of oxygen it supposes to be rejected by the root. The experiments on which it is founded require confirmation and extension.

caying vegetable matter it contains. This carbonic acid will ascend to the leaf, and will there undergo decomposition along with that which is absorbed by the leaf itself. At least we know of no function of the root or stem by which the carbonic acid derived from the soil can be decomposed and deprived of its oxygen before it reaches the leaf.

It is distinctly stated, indeed, by Sprengel,* that when the roots of a plant are in the presence of carbonic acid, the oxygen given off by the leaf is greater in bulk than the carbonic acid absorbed. But there is one observation in connection with this point which it seems to me of importance to make. The leaves supply carbon to the plant only in the form of carbonic acid, and they give off a bulk of oxygen gas not exceeding† that of the acid taken in. But if the carbon derived from the soil be also absorbed in the form of carbonic acid, and if the oxygen contained in this portion of acid is also given off by the leaf—either the quantity drawn from the soil must be small, compared with that inhaled from the air, or the oxygen given off by the leaf must, in the ordinary course of vegetation, be sensibly greater than the bulk of the carbonic acid which it absorbs.

We are too little familiar with the chemical functions of the several parts of plants to be able to pronounce a decided opinion on this point; but it appears evident that one or other of the three following conditions must obtain:—

(*a*). Either in the general vegetation of the globe the bulk of the oxygen gas given off by the leaf during the day must always be considerably greater than that of the carbonic acid absorbed by *it*; or

(*b*). The root or stem must have the power of decomposing carbonic acid and of separating and setting free its oxygen; or

(*c*). The plant can derive no considerable portion of its carbon from the soil, in the form of carbonic acid.

If the experiments hitherto made by the vegetable physiologists be considered of so decisive a character as to warrant us in rejecting the two former conditions, the third becomes also untenable.

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* See above, p. 133.

† See note to p. 201.

3°. Without dwelling at present on this point, the above considerations may be regarded as giving additional strength or probability to the conclusions we formerly arrived at (p. 87) from other premises—that the roots, besides carbonic acid, absorb certain other soluble organic compounds, which are always present in the soil in greater or less quantity, and that the plant appropriates and converts these into its own substance. Some of these organic compounds may readily, and by apparently simple changes, be transformed into the starch and woody fibre of the living vegetable. The illustration of this fact will be reserved until, in the second part of these lectures, I come to treat of the vegetable portion of soils, and of the chemical nature and constitution of the organic compounds of which it consists, or to which it is capable of giving rise.

4°. The chemical changes above explained (*a*), show how, from carbonic acid and the elements of water, substances possessed of the elementary constitution of sugar and gum may, by the natural processes of vegetable life, obtain the elements of which they consist, and in the requisite proportions. They throw no light, however, upon the mechanism by which these elements are constrained, as it were, to assume *first* the form of gum or sugar, or soluble starch, and *afterwards*, in another part of the plant, of insoluble starch and woody fibre.

It is known that the sap deposits starch and woody fibre in the stem, only in its descent from the leaf,—and it is, therefore, inferred that the action of light upon the sap, as it passes through the green parts, is necessary to dispose the elements to arrange themselves in the form of vascular fibre or lignin. And as, by the agency of nitric acid, starch appears to be convertible into woody fibre (p. 186), it is not unlikely that the soluble substances, containing nitrogen, which are present in the sap may—as diastase does upon starch—exercise an agency in transforming the soluble sugar, gum, &c., of the sap into the insoluble starch and woody fibre of the seed and the stem. We are here, however, upon uncertain ground, and I refrain from advancing any further conjectures.

Two great steps we have now made. We have seen how the germ lives and grows at the expense of the food stored up in the seed—and how, when it has obtained roots and leaves, the plant is enabled to extract from the air and from the soil such materials as, in kind and quantity, are fitted to build up its several parts during its future growth. That considerable obscurity still rests on the details of what takes place in the interior of the plant, does not detract from the value of what we have already been able to ascertain.

§ 3. *On the production of oxalic acid in the leaves and stems of plants.*

In the preceding section we have studied the origin of those substances only which form the chief bulk of the products of vegetation, and which are characterized by a chemical constitution of such a kind as enables them to be represented by carbon and water. But during the stage of vegetable growth we are now considering, other compounds totally different in their nature are also produced, and in some plants in sufficient quantity to be deserving of a separate consideration. Such is the case with oxalic acid.

The circumstances under which this acid occurs in nature have already been detailed. It is found in small quantities in many plants. The potash in forest trees is supposed to be in combination with oxalic acid, while in the lichens *oxalate of lime* serves a purpose similar to that performed by the woody fibre of the more perfect plant; it forms the skeleton by which the vegetable structure is supported, and through which its vascular system is diffused.

The production of this acid in the living plant is readily understood when its chemical constitution ($C^2 O^3$) is compared with that of carbonic acid (CO^2). For

$$\begin{array}{lcl} \text{2 of Carbonic Acid} & = & C^2\ O^4 \\ \text{1 of Oxalic Acid}\ . & = & C^2\ O^3 \\ \hline \text{Difference}\ .\ . & & \quad\ O^1 \end{array}$$

That is to say, 2 of carbonic acid are transformed into

1 of oxalic acid by the loss of 1 equivalent of oxygen—or generally, *carbonic acid by the loss of one-fourth of its oxygen may be converted into oxalic acid.*

But the leaf absorbs carbonic acid and gives off oxygen. In the lichens, therefore, which contain so much oxalic acid, a large portion of the carbonic acid absorbed is, by the action of light, deprived of only one-fourth of its oxygen, and is thus changed into oxalic acid. The same is true to a smaller extent of the sorrel leaves and stems, which owe their sourness to the presence of oxalic acid—of the leaves and stems of rhubarb also—in a still smaller degree of the beech and other large trees, in which much potash, and probably, also, of marine plants, in which much soda is found to exist. It must be owing to the peculiar structure of the leaves of each genus or natural order of plants, that the same action of the same light decomposes the carbonic acid in different degrees—evolving in some a less proportion of its oxygen, and causing in such plants the formation of a larger quantity of oxalic acid.

The fact of the production of this oxalic acid, to a very considerable amount in many plants, is a further proof of the uncertainty of those experiments from which physiologists have concluded that the leaves of plants emit a bulk of oxygen sensibly equal to that of the carbonic acid absorbed.*

I have referred the production of more or less oxalic acid in different plants to the special structure of each, and this must be true, where, in the same circumstances, different results of this kind are observed to take place—as where sorrels and sweet clovers grow side by side. Yet the influence of light of different degrees of intensity on the same plant, is beautifully shown by the leaves of the *Sempervivum arboreum*, of the *Portulacaria afra*, and other plants *which are sour in the morning, tasteless in the middle of the day, and bitter in the evening.*[*] During the night the oxygen has accumulated in these plants and formed acids containing oxygen in excess (p. 187.) As the day advances this oxygen is given off; under the influence of light the acids are decomposed, and the sourness disappears.

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* Were we permitted, in the absence of decisive experiments, to state as true what theoretical considerations plainly indicate, we should say

1°. That plants containing much oxalic or other similar acids, and not deriving much carbonic acid from the soil, must give off from their leaves a bulk of oxygen *less* than that of the carbonic acid absorbed.

2°. That plants containing no sensible quantity of such acids, nor fed by carbonic acid from the soil, may evolve oxygen sensibly *equal* in bulk to the carbonic acid absorbed.

3°. That if little of these acids be present, and much carbonic acid be absorbed from the soil, the volume of oxygen given off by the green parts of the plant must be sensibly *greater* than that of the carbonic acid they absorb.

4°. That the leaves of the pines and other trees containing much turpentine—in which hydrogen is in excess—must at all times give off oxygen in *greater* bulk than the carbonic acid they absorb. They must decompose water as well as carbonic acid, and evolve the oxygen of both.

In the juices of plants before the period of flowering, other acids also are met with besides the oxalic acid, though in much smaller quantity. As the most important of these, however, occur more abundantly in fruits, we shall consider the theory of their formation in the following section.

§ 4. *Of the chemical changes which take place between the opening of the flower and the ripening of the fruit or seed.*

The opening of the flower is the first and most striking step taken by the plant towards the production of the seed by which its species is to be perpetuated. That at this period a new series of chemical changes commences in the plant is obvious from the following facts :—

1°. That the flower leaves absorb oxygen and emit carbonic acid both by day[†] and by night (p. 187.)

2°. That they also occasionally emit pure nitrogen gas.

3°. That the juice of the maple ceases to be sweet when the flowers are matured (Liebig,) and that, in the sugar cane and beet root, the sugar becomes less abundant when the plant has begun to blossom.

These facts sufficiently indicate the commencement of new changes in the interior of plants at this period of their growth. That such changes go on until the ripening of the seed is also evident from these further observations :—

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[*] Sprengel, *Chemie*, II., p. 321.

[†] By day the absorption is the greater, but the bulk of the oxygen taken in is always greater than that of the carbonic acid given off.

1°. That the husk of the future seed, as in the corn-bearing grasses (wheat, oats, &c.,) is filled at first with a milky liquid, which becomes gradually sweeter and more dense, and finally consolidates into a mixture of starch and gluten, such as is presented by the flour of different species of corn.

2°. That the fruit in which the seeds of many plants is enveloped is at first tasteless, afterwards more or less sour, and finally sweet. In a few fruits only, as in the lime, the lemon, and the tamarind, does a sufficient quantity of acid remain to be sensible to the taste, when the seed has become perfectly ripe. The acid and cellular fibre both diminish while the sugar increases.

3°. That fruits, while green, act upon the air like the green leaves and twigs—but that, as they approach maturity, they also absorb or retain oxygen gas (De Saussure.) The same absorption of oxygen takes place when unripe fruits are plucked and left to ripen in the air (Berard.) After a time the latter also emit carbonic acid.

I.—FORMATION OF THE SEED.

In the case of wheat, barley, or other plants, which yield farinaceous seeds, we have seen that previous to flowering the chief energy of the living plant is expended in the production of the woody fibre of which its stem and growing branches mainly consist; and we have also been able to understand, in some degree, how this woody fibre is produced from the ordinary food of the plant. When the flower expands, however, the plant has in general, and especially if an annual plant, reached nearly to maturity, and woody fibre is little required. The most important of its remaining functions is the production of the starch and gluten of the seed, and of the substances which form the husk by which the seed is enveloped.

In the first stages of the plant's growth, the starch of the seed is transformed into gum and sugar, and subsequently, when the leaves are expanded, into woody fibre. In the last stages of its existence, when it is producing the seed, the sugar of the sweet and milky sap is gradually transformed into starch—that is to say, a process exactly the converse of the former takes place.

We are able, in some measure, to explain the mode and agency by which the former transformation is effected—the latter, however, is still inexplicable. We can ourselves, by the agency of diastase, transform starch into sugar; and, therefore, can readily believe such transformations to be effected in the young plant;—but we as yet know no method of *re*-converting sugar into starch; and, therefore, we can only hazard conjectures as to the way in which this change is brought about in the interior of the plant during the formation of the seed.

It is said that nitrogen is given off by the flower leaf. We know that this element is present in the colouring matter of the petal, and that it is a necessary constituent of the albumen and gluten, which are always associated with the starch of the seed. It is plain, then, that the nitrogeneous* substances contained in the sap at all periods of the plant's growth are carried up in great quantity to the flower and seed vessel. These substances are *supposed* to be concerned as immediate agents in effecting the transformations which there take place. More than this, however, we cannot as yet venture even to conjecture.

II.—RIPENING OF THE FRUIT.

In those plants again, which invest their seed with a pulpy fruit—in the grape, the lemon, the apple, the plum, &c.—other changes take place, at this period, of a more intelligible kind, and other substances are formed, on the production of which less obscurity rests. At one stage of their growth, these fruits, as has been already stated, are tasteless—in the next, they are sour—in the third, they are more or less entirely sweet.

I°. In the tasteless state they consist of little more than the substance of the leaf—of vascular, or woody fibre, filled with a tasteless sap, and tinged with the colouring matter of the green parts of the plant. For a time, this young fruit appears to perform in reference to the atmosphere the usual functions of the leaf—it absorbs carbonic acid and gives off oxygen, and thus extracts from the air a portion of the food by which its growth is promoted, and its size gradually increased.

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* Substances containing nitrogen.

II°. But after a time this fruit becomes sour to the taste, and its acidity gradually increases—while at the same time it is observed to give off a less comparative bulk of oxygen than before. Let us consider shortly the theory of the production of the more abundant vegetable acids contained in fruits.

1°. The *tartaric acid* which occurs in the grape is represented by $C^4\ H^2\ O^5$ (p. 182).

There are two ways in which we may suppose this acid to be formed in the fruit—either directly from the elements of carbonic acid and water with the *evolution* of oxygen gas—or from the gum and sugar already present in the sap aided by the *absorption* of oxygen from the atmosphere. Thus

A. 4 of CARBONIC ACID = $C^4\ \ O^8$
2 of WATER . . = $H^2\ O^2$
Tartaric Acid.
Sum . . = $C^4\ H^2\ O^{10}$ or $C^4\ H^2\ O^5 + 5O$

That is, one equivalent of tartaric acid may be formed from 4 of carbonic acid absorbed by the leaf or fruit, and 2 of the water of the sap, while 5 of oxygen are at the same time given off by the leaf. Or,

B. If Grape Sugar be $C^{12}\ H^{12}\ O^{12}$
⅓ of GRAPE SUGAR = $C^4\ H^3\ O^3$
3 of OXYGEN . . = O^3
Sum . . = $C^4\ H^3\ O^6$
Tartaric Acid. Water.
or $C^4\ H^2\ O^5 + H\ O$,

That is, by the absorption from the air of a quantity of oxygen equal to that which it already contains, grape sugar may be converted into tartaric acid and water.

In the sorrels and other sour leaved plants, which contain tartaric acid in their general sap, the acid may be formed by either of the processes above explained. In the sunshine their green parts absorb carbonic acid and evolve oxygen. If any of these green parts give off only ½ of the oxygen contained in the carbonic acid they drink in, tartaric acid may be produced (A.) In the dark they absorb oxygen and give off carbonic acid. If the bulk of this latter gas which escapes be less than that of the oxygen which enters, a portion of the sugar or gum of the sap may, as above explained (B.), be converted into tartaric acid.

We have as yet no experiments which enable us to say by which of these modes the tartaric acid is really produced in such plants—or whether it may not occasionally be compounded by both methods.

In green fruits also, in the sour grape for example, it may, in like manner, be produced by either method. The only experiments we yet possess, those of De Saussure, though not sufficient to decide the point, are in favour of the former explanation (A.) In the estimation of this philosopher, the proportion of the oxygen of the carbonic acid which is retained by the fruit, is sufficient to account for the acidity it gradually acquires.

2°. *Malic and citric acids.* These acids are represented (p. 187) by the common formulæ $C^4 H^2 O^4$. They may be produced from water and carbonic acid, if three-fourths only of the oxygen of the latter be given off. Thus

$$\begin{aligned} &\text{4 of Carbonic Acid} = C^4 \quad O^8 \\ &\text{2 of Water . . . .} = \quad H^2 O^2 \\ &\hline \\ &\text{Sum . .} = C^4 H^2 O^{10} = \overset{\text{Malic Acid.}}{\underbrace{C^4 H^2 O^4}} + 6\,O \end{aligned}$$

That such a retention of one-fourth of the oxygen of the carbonic acid occasionally takes place in the green fruit, is consistent with the observations of De Saussure. The lime and the lemon are fruits on which the most satisfactory experiments might be made with the view of finally determining this point.

III°. This formation of acid proceeds for a certain time, the fruit becoming sourer and sourer; the acidity then begins to diminish, sugar is formed, and the fruit ripens. The acid rarely disappears entirely, even from the sweetest fruits, until they begin to decay; a considerable portion of it, however, must be converted into grape sugar, as the fruit approaches to maturity. This conversion may take place in either of two ways.

1°. By the direct evolution of the excess of oxygen. Thus

$$\begin{array}{lll} \text{3 of TARTARIC ACID} = & C^{12}\,H^{6}\,O^{15} & \\ \text{6 of WATER} \;.\;.\;. = & \quad\;\; H^{6}\,O^{6} & \\ \hline \text{Sum} \;.\;.\;. = & C^{12}\,H^{12}\,O^{21} = & \overset{\text{Grape Sugar.}}{\underbrace{C^{12}\,H^{12}\,O^{12}}} + 9\,O \end{array}$$

Or grape sugar may be formed from 3 of tartaric acid and 6 of the water of the sap, by the evolution, at the same time, of 9 of oxygen. Citric and malic acids, in the same proportion, would form grape sugar by the evolution of 6 of oxygen only.

Do fruits, when they have reached their sourest state, begin thus to give off an excess of oxygen? I know of no experiments which as yet decide the point.

2°. By the absorption of oxygen and the evolution of carbonic acid. Thus in the case of tartaric acid,

$$\begin{array}{lll} \text{1 of TARTARIC ACID} = & C^{4}\,H^{2}\,O^{5} & \\ \text{1 of OXYGEN} \;.\;.\;.\;. = & \qquad\;\; O^{1} & \\ \hline \text{Sum} \;.\;.\;. = & C^{4}\,H^{2}\,O^{6} = & \overset{\text{1-6th of Grape Sugar.}}{C^{2}\,H^{2}\,O^{2}} + \overset{\text{Carbonic Acid.}}{2\,CO^{2}} \end{array}$$

Where one of oxygen is absorbed and 2 of carbonic acid given off. Or in the case of the malic and citric acids,

$$\begin{array}{lll} \text{1 of MALIC ACID} = & C^{4}\,H^{2}\,O^{4} & \\ \text{2 of OXYGEN} \;.\;. = & \qquad\;\; O^{2} & \\ \hline \text{Sum} \;.\;. = & C^{4}\,H^{2}\,O^{6} = & \overset{\text{1-6th of Grape Sugar.}}{C^{2}\,H^{2}\,O^{2}} + \overset{\text{Carbonic Acid.}}{2\,CO^{2}} \end{array}$$

Where 2 of oxygen are absorbed and 2 of carbonic acid given off.

We know from the experiments of Berard that, when unripe fruits are plucked, they do not ripen if excluded from the access of oxygen gas—but that in the air they ripen, absorbing oxygen at the same time, and giving off carbonic acid. This second method (2°) therefore exhibits the more probable theory of the ripening of fruits *after they are plucked*; and if—*as they become coloured*—fruits imitate the petals of the flower in absorbing oxygen from the air and giving off carbonic acid, it will also represent the changes which take place when they are permitted to ripen on the tree.

During the ripening of the fruit, it has been stated that the woody or cellular fibre it contains gradually diminishes, and is converted into sugar. This is familiarly noticed in some species of hard or winter pears. In sour fruit, the cellular fibre seldom exceeds 2½ per cent. of their whole weight;—in ripe fruits, however, it is still less, and as the constitution of this substance is so analogous to that of grape sugar, there is no difficulty in understanding that it may be readily converted into the latter, though the immediate agency by which the transformation is effected is as yet unknown to us.

§ 5. *Of the chemical changes which take place after the ripening of the fruit and seed.*

When the seed is fully ripe, the functions of annual plants are discharged. They no longer require to absorb and decompose carbonic acid, for their growth is at an end. Their leaves begin, therefore, to take in oxygen only, become yellow, and prepare along with the entire plant, for being finally resolved again into those more elementary substances from which they were originally compounded.

On trees and perennial plants, however, a further labour is imposed. In the ripened seed they have deposited a supply of food sufficient to sustain the germ that may spring from it, until it is able to seek food for itself; but the young buds already formed,—and which are to shoot out from the stem and branches in the ensuing spring,—are in reality so many young plants for which a store of food has yet to be laid up in the inner bark, and in the wood of the tree or shrub itself.

In the autumn, the sap of trees and permanent shrubs continues to flow rapidly till the leaf withers and falls, and the food of the plant is converted partly into woody fibre, as was the case during the earlier period of the year, and partly into starch. The former is deposited beneath the inner bark to form the new layer of wood by which the tree is annually enlarged; the latter—partly in the same locality, as in the birch and pine—partly throughout the substance of the wood itself, as in the willow—while in the palm trees and cycadeæ, it is intermingled with the central pith. The chemical changes by which the food is capable of being converted into these substances have already been considered. They proceed during the entire autumn, do not cease so long as the sap continues to move, and even in the depth of winter slowly and silently operate in storing up farinaceous matter—in readiness, like the starch in the seed, to minister to the nourishment of the young bud, when the warmth of the coming spring shall awaken it from its long sleep.

§ 6. *Of the rapidity with which these changes take place, and the circumstances by which they are promoted.*

But remarkable as those chemical changes are, the rapidity with which they sometimes take place is no less surprising.

From carbonic acid and water we have seen that the plant, by very intelligible processes, can extract the elements of which its most bulky parts consist—and can build them up in many varied ways, most of which are probably beyond the reach of imitation. But who can understand or explain the extraordinary activity which pervades the entire vascular system of the plant, when circumstances are favourable to its growth?

A stalk of wheat has been observed to shoot up three inches in as many days, of barley six inches in the same time, and a vine twig almost two feet, or eight inches a day (Du Hamel). Cucumbers have been known to acquire a length of twenty-four inches in six days, and in the Botanic Garden at Brussels I was shown a bamboo five inches in diameter, which had increased in height nine feet in twenty-seven days, sometimes making a progress of six to eight inches in a day. In our climate we meet with few illustrations of the rapidity with which plants are capable of springing up in the most favourable circumstances, and the above examples probably give us only an imperfect idea of the velocity with which the bamboo, the palm, the tree fern, and other vascular plants, may grow in their native soil and climate. And with what numerous and complicated chemical changes is the production of every grain of the substance of these plants attended—how rapidly must the food be selected and absorbed from the air and from the soil—how quickly transformed and assimilated!

The long period of time during which, year after year, these changes may proceed in the same living vessels, or in the same tree, is no less wonderful. Oaks have lived to an age of 1500 or 2000 years—Yew trees to 3000 years—and other species are mentioned as having flourished from 4500 to 6000 years; while even a living rose tree (*rosa canina*) is quoted by Sprengel as being already upwards of 1000 years old.*

The rapidity of the growth of a plant, and the length of its life, are equally affected by circumstances. On a knowledge of these circumstances, and of the means of controlling or of producing them, the enlightened practice of agriculture is almost entirely dependent.

Over the *natural* conditions on which vegetation in general depends, we can exercise little control. By hedge-rows and plantations we can shelter exposed lands, but, except in our conservatories and hot-houses, the plants we can expect to cultivate with profit will always be determined by the general climate in which we live. So the distribution of rain and sunshine are beyond our control, and though it is ascertained that a thundery condition of the atmosphere is remarkably favourable to vegetable growth,† we cannot hope that such a state of the air will ever be induced, at the pleasure or by the agency of man. But under the same *natural* conditions of climate, there are many *artificial* methods by the use of which it is within our power to accelerate the growth, and to increase the produce of the most valuable objects of ordinary culture.

Thus the germination of seeds in general is hastened by watering with a solution of chlorine (Davy), or of iodine or bromine (Blengini), and Davy found that radish seed which germinated in two days when watered with solutions of chlorine or sulphate of iron, required three when watered with very dilute nitric acid, and five with a weak solution of sulphuric acid.

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* Sprengel, *Lehre vom Dünger*, p. 76.

† *Ibid*, p. 73.

It is familiarly known also in ordinary husbandry, that the application of manures hastens in a similar degree the development of all the parts of plants during every period of their growth—and largely increases the return of seed obtained from the cultivated grains. Ammonia and its compounds likewise, and nitric acid and its compounds, with many other saline substances existing in the mineral kingdom and occurring in soils, or which are produced largely in our manufactories, have been found to produce similar effects.

It would be out of place here to enter upon the important and interesting field opened up to us by a consideration of the influence exercised by these and other substances, in modifying both in kind and in degree the chemical changes which take place in living vegetables. The true mode of action of such substances—their precise effects—the circumstances under which these effects are most certainly produced—and the theoretical views on which they can be best accounted for—will form a subject of special and detailed examination in the third part of the present lectures.

LECTURE VIII.

How the supply of food for plants is kept up in the general vegetation of the globe. Proportion of their food drawn by plants from the air. Supply of carbonic acid. Supply of ammonia and nitric acid. Production of both in nature. Theory of their action on living vegetables. Concluding observations.

Having shown in the preceding Lecture in what way, and by what chemical changes, the substances of which plants chiefly consist may be produced from those on which they live,—there remains only one further subject of inquiry in connection with the organic constituents of plants.

Plants, as we have already seen, derive much of their sustenance from the carbonic acid of the atmosphere; yet of this gas the air contains only a very small fraction, and in so far as experiments have yet gone, this fractional quantity does not appear to diminish—how, then, is the supply of carbonic acid kept up?

Again, plants most probably obtain much of their nitrogen either from ammonia or from nitric acid; and yet, neither in the soil nor in the air do these compounds permanently exist in any notable quantity,—whence then is the supply of these substances brought within the reach of plants?

The importance of these two questions will appear more distinctly, if we endeavour to estimate how much of their carbon plants really draw from the atmosphere—and how much of the nitrogen they contain must be derived from sources not hitherto pointed out.

§ 1. *Of the proportion of their carbon which plants derive from the atmosphere.*

On this subject it is perhaps impossible to obtain perfectly accurate results. Several series of experiments, however, have been published, which enable us to arrive at very useful approximations in regard to the proportion of their carbon which plants, growing in a soil of ordinary fertility, and in such a climate as that of Great Britain, actually extract from the air by which they are surrounded.

1°. In an experiment made in 1824, upon common borage (Borago officinalis), Lampadius found that after a growth of five months (from the 3rd of April to the 6th of September) this plant produced ten times as much vegetable matter as the soil in which it grew had lost during the same period.* In other words, *it had drawn nine-tenths of its carbon from the air.*

2°. The experiments of Boussingault were made if not with more care, at least upon a greater number of plants, and were protracted through a much longer period. It is necessary that we should understand the principle on which they were conducted, in order that we may be prepared to place confidence in the determinations at which he arrived.

If we were to examine the soil of a field on which we are about to raise a crop of corn—and should find it to contain a certain per centage, say 10 per cent. of vegetable matter (or 5 per cent. of carbon);—and after the crop is raised and reaped should, on a second examination, find it to contain exactly the same quantity of carbon as before, we could not resist the conviction, that, with the exception of what was originally in the seed, the plant during its growth had drawn from the air all the carbon it contained. The soil *having lost none, the air must have yielded the whole supply.*

Or if after examining the soil of our field we mix with it a supply of farm-yard manure, containing a known weight, say one ton of carbon, and when the crop is reaped find as before that the per-centage of vegetable matter in the soil has suffered no diminution,† we are justified in concluding that the crop cannot, at the utmost, have derived from the soil any greater weight of its carbon than the ton contained in the manure which had been added to it.

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* The above experiment may have been correctly made, but the result appears at first sight too startling to be readily received as indicative of the proportion of their sustenance drawn by plants from the air *in the general vegetation of the globe.*

† I need scarcely remark that, in the hands of a good farmer, who

Such was the principle on which Boussingault's experiments were conducted. He determined the per-centage of carbon in the soil before the experiment was begun—the weight added in the form of manure—the quantity contained in the series of crops raised during an entire rotation or course of cropping, until in the mode of culture adopted it was usual to add manure again—and lastly, the proportion of carbon remaining in the soil. By this method he obtained the following results in pounds per English acre, in three different courses of cropping, and on the same land:—

	Carbon in the Manure.	Carbon in the Crops.	Difference, or Carbon derived from the air.	REMARKS.
First Course	2513	7544	5031	The first was a 5 years' course—of potatoes or red beet with manure, wheat, clover, wheat, oats; the second and most productive rotation was abandoned on account of the climate; the third was a 3 years' course.
Second do.			6839	
Third do.			3921	

The result of the first course indicates that—the land remaining in equal condition at the end of the four years as it was at the beginning—the crops collected during these years contained three times the quantity of carbon present in the manure, and *therefore the plants, during their growth, must on the whole have derived two-thirds of their carbon from the air.*

It will be shown in a subsequent section that even when the soil is lying naked the animal and vegetable matter it contains is continually undergoing diminution, owing to decomposition and the escape of volatile substances into the

keeps his land in *good heart*—the quantity of organic matter in the soil at the *end* of his course of cropping should be as great, at least, as it was at the beginning of his rotation, before the addition of the manure.

air. It is fair, therefore, to assume that a considerable portion of the carbon of the manure and of the soil would naturally disappear during the four years' cropping above-mentioned, and that, therefore, the proportion of carbon derived from the air in Boussingault's experiments, must have been really considerably greater than is indicated by the numerical results.

Let two-thirds of the entire quantity of carbon contained in a series of crops be taken as the average* proportion which, on cultivated land in our climate, must be derived from the air in the form of carbonic acid—and let the average weight of the dry crop reaped be estimated at a ton and a half per acre. Then, if the crop contain half its weight of carbon,† the plants grown on each acre must annually extract from the air 10 cwt. or 1120 lbs. of carbon in the form of carbonic acid.

§ 2. *Of the relation which the quantity of carbon extracted by plants from the air, bears to the whole quantity contained in the atmosphere.*

But the question will here at once suggest itself to you—does not the quantity thus extracted from the air really form a very large proportion of the whole weight of carbon which is contained in the atmosphere? A simple calculation will give us clear ideas in regard to this interesting point.

We have already seen that, by the results of De Saussure, the average quantity of carbonic acid in the atmosphere of our globe may be estimated at $\frac{1}{2500}$ part of its entire bulk. This is equal very nearly to $\frac{3}{5000}$ of its weight.‡ Or taking the whole weight of the atmosphere at 15 lbs. on the square inch—that of the carbonic acid will be 0·009 lbs., or 63 grs. per square inch. But as carbonic acid contains only 27⅔ per cent. of its weight of carbon, the weight of this element which presses on each square inch of the earth's surface is only 17⅖ (17·39) grs. Upon an acre this amounts to 7 tons.*

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* Lecture II., p. 35.

† Boussingault states, that of all the plants usually cultivated for food—so far as his experiments have gone—the Jerusalem artichoke draws the largest portion of its sustenance from the air—or *yields the greatest weight of food from the smallest weight of manure.* It is true generally indeed that all those plants, which, like the Jerusalem artichoke and the white carrot, grow freely on sandy soils containing little vegetable matter and with the addition of little manure, extract the greatest proportion of their sustenance from the air. Such plants, therefore, are likely to prove the most profitable articles of culture where such soils and a scarcity of manure simultaneously prevail.

‡ The mean of 225 experiments made by De Saussure between 1827

But if the crop on each acre of cultivated land annually extracts from the air half a ton of carbon, the whole of the carbonic acid in the atmosphere would sustain such a vegetation over the entire globe for 14 years only. And if we even suppose such a vegetation to extend over one hundredth part of the earth's surface only, it still appears sufficient to exhaust the carbonic acid of the air in 1400 years.

A very short period, compared even with the limits of authentic history, has yet elapsed since experiments began to be made on the true constitution of the atmosphere; we have no very trustworthy data, therefore, on which to found a confident opinion in regard to the permanence of the proportion of carbonic acid which it now contains. The later observations of De Saussure do give a considerably lower estimate of the quantity of this acid in the air than that which was deduced from the results of the earlier experimenters; but the imperfection of the modes of analysis formerly adopted was too great, to justify us in reasoning rigorously from the inferences to which they led. We cannot

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and 1829 gave as above stated about 4–10000 or 1–2500th part for the mean bulk of the carbonic acid in the air, which is nearly 6–1000ths of its whole weight. Among these observations the maximum was 5·8 ten thousandths, the minimum 3·15. If we take the maximum *bulk* at 6–10000ths of the air—the maximum *weight* of the carbonic acid is nearly 9–10000ths of that of the atmosphere. In elementary works it is generally stated in round numbers at 1–1000th of the weight of the air, but if the best experimental results we possess are to be any guide to us, this is at least one-third too high.

It is also of consequence to remark, that this estimate of the whole weight of the carbonic acid in the air is founded on the supposition that, in the highest regions of the atmosphere, the carbonic acid is present in a proportion nearly equal to that in which it is found immediately above the earth's surface—which is by no means established.

* 15,583 lbs.—an acre being 4840 square yards, containing each 1296 square inches.

safely conclude from them that the proportion of carbon in the atmosphere has really diminished to any sensible extent during this limited period; while the recorded identity of all the phenomena of vegetation render it probable that the proportion has not sensibly diminished even within historic times.

From what sources, then, is the supply of carbonic acid in the atmosphere kept up?—and if the proportion be permanent, by what compensating processes is the quantity which is restored to the atmosphere produced and regulated?

§ 3. *How the supply of carbonic acid in the atmosphere is renewed and regulated.*

On comparing, in a previous lecture, the quantity of rain which falls with that of the watery vapour actually present in the air, we saw reason to believe that even in a single year the same portion of water may fall in rain or dew and ascend again in watery vapour several successive times. Is it so also with the carbon in the air? Does that which feeds the growing plant to-day, again mount up in the form of carbonic acid at some future time, ready to minister to the sustenance of new races, and to run again the same round of ever-varying change? Such is, indeed, the *general* history of the agency of the carbonic acid of the atmosphere; but when once it has been fixed in the plant it must pass through many successive changes before it is again set free. The conditions, also, under which it is restored to the atmosphere are so diversified—and the agencies by which, in each case, it is liberated are so very distinct, as to require that the several modes by which the carbon of plants is reconverted into carbonic acid and returned to the air, should be made topics of separate consideration.

I.—ON THE PRODUCTION OF CARBONIC ACID BY RESPIRATION.

The air we breathe when it is drawn *into* the lungs, contains $\frac{1}{2500}$th of its bulk of carbonic acid; when it returns again *from* the lungs, the bulk of this gas amounts, on an average,* to $\frac{1}{25}$th of the whole; or *its quantity is increased one hundred times.*

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* It varies in different individuals from 2 to 8 per cent. of the expired

The actual bulk of the carbonic acid emitted from the lungs of a single individual in 24 hours varies exceedingly; it has been estimated, however, on an average, to contain upwards of five ounces of carbon.[*] A full grown man, therefore, gives off from his lungs, in the course of a year, upwards of 100 lbs. of carbon in the form of carbonic acid.

If the quantity of carbon thus evolved from the lungs be in proportion to the weight of the animal, a cow or a horse ought to give off six times as much as a man.[†] From indirect experiments, however, Boussingault[‡] estimated the quantity of carbon actually lost in this way by a cow at 2200 grains in 24 hours, and by a horse at 2400 grains. This differs so little from the quantity expired by a healthy man, as to render it very doubtful whether the weight of carbon which escapes from the lungs of different animals bears any direct proportion to their relative bulks or weights.

If we suppose each inhabitant of Great Britain, young and old, to expire only 80 lbs. of carbon in a year, the twenty millions would emit seven hundred thousand tons; and, allowing the cattle, sheep, and all other animals, to give off twice as much more, the whole weight of carbon returned to the air by respiration in this island would be about two millions of tons, or the quantity abstracted from the atmosphere by four millions of acres of cultivated land.

Whence is all this carbon derived? It is a portion of that which has been conveyed into the stomach in the form of food. Suppose the carbon contained in the daily food of a full grown man to amount to one pound—which is a large allowance—then it appears that, by the ordinary processes of respiration, *at least one-third of the carbon of his food is daily returned into the air.*

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air. In animals it varies also with the species. The air from the lungs of a cat contains from 5½ to 7 per cent., of a dog from 4½ to 6¼, of a rabbit from 4 to 6, and of a pigeon from 3 to 4 per cent. of the whole bulk. —Dulong, *Annal. de Chim. et de Phys., third Series, I., p.* 455.

[*] Davy, and Allen and Pepys, estimated the weight of carbon evolved in a day at upwards of 11 ounces, a quantity which all writers have concurred in receiving with suspicion.

[†] Estimating the ordinary weight of a man at 150, and of a cow at 800 to 900 lbs.—See Sprengel, *Lehre vom Dünger. p.* 208.

[‡] *Ann. de Chim. et de Phys.*, lxxi., pp. 127 and 136.

In other animals the proportion returned may be different from what it is in man, yet the life of all depends on the emission to a certain extent of the same gas.* And since all are sustained by the produce of the soil, it is obvious that the process of animal respiration is one of those methods, by which it has been provided that a large portion of the vegetable productions of the globe should be almost immediately resolved into the simpler forms of matter from which it was originally compounded, and again sent up into the air to minister to the wants of new races.

II.—ON THE PRODUCTION OF CARBONIC ACID BY COMBUSTION.

Another important source of carbonic acid is familiar to us in the results of artificial combustion.

In the previous lecture I have shown how, by the action of the sun's rays upon the leaf, the carbonic acid absorbed from the atmosphere is deprived of its oxygen, and its carbon afterwards united to the elements of water for the production of woody fibre. During the process of combustion, this labour of the living leaf is undone—the carbon is made to combine anew with the oxygen of the atmosphere, and the vegetable matter is resolved again into carbonic acid and water.

Thus, when wood (woody fibre) is burned in the air, oxygen disappears, and carbonic acid and watery vapour are alone produced. The theory of this change is simple.

It will be recollected (p. 200) that in forming an equivalent of woody fibre or of sugar, 24 of oxygen were given off, chiefly by the leaf—so in again resolving these substances into carbonic acid and water, 24 of oxygen are absorbed. Thus—

$$\begin{array}{lcll} \text{1 of Woody Fibre} & = & C^{12}\,H^{8}\,O^{8} & \\ \text{24 of Oxygen} \quad . & = & \qquad\;\; O^{24} & \\ \cline{3-3} \text{Sum} \quad . & = & C^{12}\,H^{8}\,O^{32} & = \overset{\text{12 of Carbonic acid.}}{12CO^{2}} + \overset{\text{8 of Water.}}{8HO} \end{array}$$

$$\begin{array}{lcll} \text{Or, 1 of Cane Sugar} & = & C^{12}\,H^{10}O^{10} & \\ \text{24 of Oxygen} \quad . & = & \qquad\;\; O^{24} & \\ \cline{3-3} \text{Sum} \quad . & = & C^{12}\,H^{10}\,O^{34} & = \overset{\text{12 of Carbonic acid.}}{12CO^{2}} + \overset{\text{10 of Water.}}{10HO} \end{array}$$

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* That the proportion *must* be less in the larger animals is certain,

The same law holds in regard to all other vegetable substances. They are resolved into carbonic acid and water, in proportions which necessarily vary with the chemical constitution of each.

It applies also to all bodies of vegetable *origin*, among which nearly all combustible minerals may be reckoned. The peat and coal we burn in our houses and manufactories, when supplied with a sufficiency of atmospheric air, are resolved during combustion into carbonic acid and watery vapour.

Some vegetable substances contain a small quantity of nitrogen. When these are burned, this nitrogen escapes into the atmosphere,—generally in an uncombined state,—and mingles with the air. So in animal substances, nearly all of which contain nitrogen as an essential constituent. During perfect combustion the whole of the carbon is dissipated in the form of carbonic acid, while the nitrogen rises along with it in an elementary state.

The result of this uniform subjection of all combustible matter to the operation of this one law, is the constant production on the surface of the globe of a vast quantity of carbonic acid;—the *re*-conversion of large masses of organic matter into the more elementary compounds from which it was originally formed.

How interesting it is to contemplate the relations, at once wise and beautiful, by which through the operation of such laws, dead organic matter, intelligent man, and living plants, are all bound together! The dead tree and the fossil coal lie almost useless things in reference to animal and vegetable life,—man employs them in a thousand ways as ministers to his wants, his comforts, or his dominion over nature—and in so doing, himself directly though unconsciously ministers to the wants of those vegetable races, which seem but to live and grow for his use and sustenance.

It is impossible to say what proportion of the carbon ab-

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since the daily food of a cow may be stated generally as equivalent to 25 lbs. of hay, containing upwards of 10 lbs. of carbon. If one-third of this were given off from the lungs, the quantity of carbon (3⅓ lbs.) evolved would be ten times greater than was indicated by the experiments of Boussingault, and nearly double of what the weight of a cow, compared with that of a man, requires.

sorbed during the general vegetation of the globe, is thus annually restored to the atmosphere by the burning of vegetable matter. That it must be very great, will appear from the single fact, that by far the greater part of the globe is dependent for its supply of fuel on the annual produce of its forests;—while even in those more favoured countries where mineral coal abounds, the quantity of wood consumed by burning falls but little short of the entire yearly growth of the land.

In connection with this subject, I must draw your attention to one interesting, as well as important, fact. I have spoken of coal as a substance of vegetable origin, and there is no doubt that all the carbon it contains once floated in the air in the form of carbonic acid. But the period when it was so mixed with the atmosphere, is remote almost beyond conception. When, therefore, we raise coal from its ancient bed and burn it on the earth's surface, *we add to the carbon of the air a portion which has not previously existed in the atmosphere of our time.*

The coal consumed in Great Britain alone is estimated at 20 millions of tons, containing on an average at least 70 per cent., or 14 millions of tons of carbon. But if the annual produce of an acre of cultivated land contain half a ton (p. 219) of carbon derived from the air, the coal consumed in this country would supply carbonic acid to the crops grown upon 28 millions of acres. Or, since in Great Britain about 34 millions of acres are in cultivation (p. 4), *the coal we annually consume produces a quantity of carbonic acid which is alone sufficient to supply food to the crops that grow upon seven-eighths of the arable land of this country.*

III.—PRODUCTION OF CARBONIC ACID BY THE NATURAL DECAY OF VEGETABLE MATTER. LAW OF THIS DECAY.

Over large tracts of country in every part of the globe, the vegetable productions of the soil are never cropped or gathered, but either accumulate—as occasionally in our peat bogs; or decay and gradually disappear—as in the jungles of India or in the tropical forests of Africa and Southern America.

The *final* results of this decay are the same as those which attend upon ordinary combustion, but the conditions under which it takes place being different, the *immediate* results are to a certain extent different also.

When a vegetable substance is burned in the air, the oxygen of the atmosphere is the only material agent in effecting the decomposition. The carbon of the burning body unites *directly* with this oxygen and forms carbonic acid.

In the natural process of decay, however, at the ordinary temperature of the atmosphere, vegetable matter is exposed to the action of both air and water; these both co-operate in inducing and carrying on the decomposition, and hence carbonic acid is not, as in the case of combustion, the chief or immediate result.

A detail of all the steps through which vegetable matter is known to pass before it is finally resolved into carbonic acid and water, would be difficult for you to understand, and is here unnecessary. A general view of the way in which by the united agency of air and water, the decay of organic substances is effected and promoted, may be made very intelligible, and will sufficiently illustrate the subject for our present purpose.

In combustion, as we have seen, the *whole* of the vegetable substance is resolved directly into carbonic acid and water, at the expense of the oxygen of the atmosphere. In natural decay a small and variable portion only is so changed, but to the extent to which this change does take place carbonic acid is directly formed and sent up into the air. Suppose such a change—a slow combustion in reality—to take place to a certain extent, and let us consider what becomes of the remainder of the vegetable matter.

1°. If we add

6 of Carbonic Acid . . $= C^6 \quad O^{12}$ to
6 of Light Carburetted Hydrogen ($C H^2$) $= C^6 \ H^{12}$ we have

The sum . . $= C^{12} H^{12} O^{12}$; or, one of grape sugar;—that is, one of grape sugar may be formed out of the elements of 6 of carbonic acid, and 6 of light carburetted hydrogen. Or, conversely, grape sugar being already produced, it may be resolved or decomposed into these two compounds in the same proportions, without the aid of the oxygen of the atmosphere.

2°. So if to

1 of Woody Fibre $= C^{12}\ H^8\ O^8$ we add
4 of Water . . $= \quad H^4\ O^4$

We have, as before, $C^{12}\ H^{12}\ O^{12} = \overset{\text{Carbonic Acid.}}{6\ CO^2} + \overset{\text{Light Carburetted Hydrogen.}}{6\ CH^2}$

Or by the aid of the elements of 4 atoms of water, woody fibre may be resolved into 6 of carbonic acid and as many of light carburetted hydrogen.

3°. Again, in the case of a vegetable acid, if to

1 of Tartaric Acid $= C^4\ H^2\ O^6$ we add
1 of Oxygen . . $= \quad O^1$

We have $C^4\ H^2\ O^6 = \overset{\text{Carbonic Acid.}}{3\ C\ O^2} + \overset{\text{Light Carburetted Hydrogen.}}{C\ H^2}$

That is, by the aid of one of oxygen from the air, one of tartaric acid may be resolved into 3 of carbonic acid, and 1 of light carburetted hydrogen. It is easy to see how any other of the more common vegetable productions may—either at the expense of its own elements, as in grape sugar—or by the aid of those of water, as in woody fibre—or of the oxygen of the atmosphere, as in tartaric acid—be resolved into carbonic acid and light carburetted hydrogen, in certain proportions.

Now, such a resolution does really take place to a considerable extent in nature, during the decay of organic substances in moist situations. Hence the evolution of light carburetted hydrogen from dead vegetable matter in marshy places and stagnant pools—hence the production of the same gas in compost heaps, and especially in rich and heated farm-yard manure—and hence also its occurrence in such vast quantities in many of our coal mines.

You will now be able to appreciate one of the reasons why this light carburetted hydrogen has been supposed by some physiologists (p. 65,) to contribute as food to the ordinary nourishment of plants. It is produced in nature in many and varied situations, and it has been found by experiment to exercise a visible influence upon the growth of plants;—being so produced where young plants grow, is it never imbibed by them?—being possessed of this influence, is it entrusted with no control over the general vegetation of the globe?

However this may be, by far the greatest portion of both these gases escapes into the air;—the carbonic acid to fulfil those purposes which have already been considered,—the light carburetted hydrogen to undergo a further change, by which it also is resolved into carbonic acid and water. Thus, if to

$$\left.\begin{array}{l}\text{1 of Light Carburet-}\\ \quad\text{ted Hydrogen}\end{array}\right\} = CH^2 \qquad \text{we add}$$

$$\text{4 of Oxygen} \;.\;.\;.\;. = \qquad O^4$$

$$\overline{}\;\text{Carbonic Acid.}\quad\text{Water.}$$

$$\text{We have} \;. \quad CH^2\,O^4 \text{ or } CO^2 + 2HO$$

Or one of this gas with 4 of oxygen may be changed into 1 of carbonic acid and 2 of water.

Now, when this gas escapes into the air it becomes diffused through a large excess of oxygen, and is thus ready, at any instant, to be decomposed. Through the atmosphere streams of electricity are continually flowing, and every wandering spark that passes athwart a portion of this mixture decomposes so much of the light gas, and produces in its stead the equivalent proportions of carbonic acid and watery vapour. Thus it happens that of the vast quantity of this and other combustible gases which are continually escaping into the air, so few traces are discernible even by the aid of the most refined processes of art. By a wise provision of nature such substances as are void of use to either animals or plants, if not speedily removed from the air altogether, are there converted into such new forms of matter as are fitted to minister to the necessities of living beings.

Though therefore in the natural decay of vegetable matter in the presence of air and moisture, a certain portion of its carbon escapes into the air in the form of light carburetted hydrogen—this compound is but a step towards the final change into carbonic acid and water. In the soil the vegetable matter is continually undergoing decay, various substances are produced in greater or less quantity, some solid, some liquid, and some gaseous like the light gas of which we have been speaking,—but all of them, like this gas, are only hastening—some by one road, so to speak, and some by another—towards that final destination which sooner or later they are all fated to reach; when in the form of carbonic acid and water they shall be in a condition to minister again to the nourishment of all plants.

While in the soil some part of this vegetable matter assumes forms which are capable of entering again into the roots of living plants, and, without further resolution in the air, of being converted by the living plant into portions of its own substance. The nature and composition of these forms of matter, so far as they are known, will be considered in a subsequent lecture.*

It is upon the *final* result of this natural decay to which all vegetable matter is subject, that the carbonic acid of the atmosphere depends for its largest supplies. The rapidity with which organised bodies perish, and become resolved into gaseous compounds, depends partly upon the climate and partly on the nature of the substances themselves,—but all hurry forward to the same end, and it is with difficulty that we are able for a time to arrest or even to retard their steps. It is by this perpetual and active obedience of all dead matter to one fixed law that the existing condition of things is maintained;—and thus it happens that either by the respiration of the animals which live upon it, by the process of combustion, or by that of spontaneous decay, the entire crop of vegetable produce is *apparently*, year by year—taking the average of a series of years—resolved into the forms of matter from which it was originally built up;—and the substances on which plants feed at length restored to the air in the precise proportion in which they have been taken from it.

VI.—NATURAL EVOLUTION OF CARBONIC ACID IN VOLCANIC COUNTRIES.

The above *apparent* conclusion would be absolutely true, were there no causes in operation by which the restoration to the air of a portion of the carbon of animal and vegetable substances is prevented—and no other sources, independent of existing organic matter, from which carbonic acid may be supplied to the air.

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* See in Part II. the Lecture, "*On the constitution of soils.*"

If the whole of the carbon be not returned to the air, the carbonic acid of the atmosphere may be undergoing diminution; while—if a large supply be constantly poured into the air from sources independent of vegetable matter, the proportion of carbonic acid may be continually on the increase.

We have seen that the combustion of fossil coal adds to the air a large quantity of carbonic acid which has never before existed in the atmosphere of our time. In many volcanic districts also, carbonic acid is observed to issue in large quantity from cracks and fissures in the earth;—accompanied sometimes by water, forming mineral springs, from which the copious emission of gas is readily perceived; more frequently, perhaps, rising up alone, and thus escaping general observation.

It must obviously be exceedingly difficult to estimate the quantity of gas which rises into the air in such circumstances over an extensive tract of country, fractured and broken up by volcanic agency—where the outlets are numerous, and the rate at which the gas escapes very variable. That in many localities it must be very great, however, there can be no question. In the ancient volcanic district of the Eifel, comprising an area of many square miles around the Laacher See, on the left bank of the Rhine, the annual evolution of carbonic acid from springs and fissures has been estimated by Bischof at not less than 100,000 tons, containing 27,000 tons of carbon. In many other districts, especially where active volcanoes exist, the volume of gas given off may be quite as great, though no attempts have hitherto been made to estimate its real amount.

Yet though absolutely large, the quantity of carbonic acid disengaged in this way from the earth, is really small when compared either with the entire quantity supposed to be present in the atmosphere, or with that which is required for the growth of the yearly vegetation of the globe. Suppose that from a thousand spots on the earth's surface a quantity of carbonic acid equal to the above estimate of

Bischof escapes constantly into the air, the weight of carbon (27 millions of tons) thus diffused through the atmosphere would be only equal to that which is yearly drawn from the air by 54 millions of acres of land under cultivation (p. 219), and only twice as much as that contained in the coal which is annually consumed in Great Britain alone.

Still if the *whole* of the carbon contained in the produce of the general vegetation of the globe be ultimately restored to the air,—either by the respiration of animals, by the natural and slow decay of vegetable matter, or by the more rapid process of combustion,—the constant addition of carbonic acid derived from volcanoes, and from the combustion of fossil coal, should gradually, though slowly, augment the proportion of this gas in the air we breathe;—unless it be perpetually undergoing a permanent diminution, to at least an equal extent, from the operation of other causes. In reference to this point there are three circumstances which are proper to be considered:—

1°. It has been observed that, as we recede from the land and approach the centre of great lakes, or sail into the open sea, the quantity of carbonic acid in the air gradually diminishes. It is therefore inferred that the sea is constantly, and to a sensible extent, absorbing carbonic acid from the atmosphere, without afterwards restoring it, so far as is yet known, by any compensating process.

2°. The waters which flow into the sea or great lakes constantly bear down with them portions of animal and vegetable matter. These fall along with the mud which the waters hold in suspension, and are permanently imbedded in the deposits of clay, silt, and sand, which are continually in the course of formation.

3°. In many parts of the world, especially in the latitudes North and South of 45°, vegetable matter accumulates in the form of peat, becomes buried beneath clay and sand, and thus is prevented from undergoing the ordinary process of natural decay.

It is impossible to say how much carbon is permanently withdrawn from the atmosphere by these several agencies. There is reason to believe that it is quite as great as the quantity added to the air by the combustion of coal, and by the evolution of carbonic acid in volcanic districts. Indeed, the supply from these two sources appears to return only a small portion of that carbonic acid which is abstracted from the air by the agencies just stated, and which have been in operation during every geological epoch.

Conclusions.—The general conclusions, therefore, which we seem justified in drawing in regard to the supply of carbonic acid to the atmosphere are as follow:—

1°. That a large portion of the carbonic acid absorbed by plants is immediately and directly restored to the air by the respiration of the animals which feed upon vegetable productions.

2°. That a still larger portion is more slowly returned by the gradual re-conversion of vegetable substances into carbonic acid and water during the process of natural decay.

3°. That *nearly all* the remainder is given back in the results of ordinary combustion.

4°. That a further portion, which has not previously existed in the atmosphere of our time, is conveyed to it by the burning of fossil fuel, and by the emission of carbonic acid from cracks and fissures in the surface of the earth; yet that the quantity thus added cannot be supposed to exceed that which is constantly and *permanently* separated from the atmosphere by other causes.

The balance of all the evidence we possess is probably in favour of the opinion that the carbonic acid in the atmosphere is slowly diminishing; we have, however, no satisfactory evidence either from theory or experiment that it has undergone any sensible diminution in our time.*

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* In another work (*Chemical Geology*) now preparing for publication, I have discussed this question in connection with purely Geological considerations and without reference *to our time;* but it would be out of place to introduce here any train of reasoning which is not calculated to throw light on the phenomena of the existing vegetation of the globe.

§ 4. *Of the supply of Ammonia to plants.*

In a previous lecture it has been shown that in our cultivated fields plants derive a portion of their nitrogen from the manure which is added to the soil. But the quantity of this element present in the manure, supposing it all taken up and appropriated by the plant, is seldom equal to that contained in the series of crops which this manure assists in raising.

Thus, in the experiments of Boussingault already described (p. 215), the manure added previous to the first, or four years' course, contained 157 parts of nitrogen, while the crops contained 251 parts,—or *nearly two-thirds more than could be derived from the artificial manure.*

Whence is this excess of nitrogen derived, and in what form does it enter into the plant? Liebig replies to these questions, that the whole of the nitrogen absorbed by plants enters in the state of ammonia, and that the excess above what is present in the manure is drawn either from the soil or from the air. This opinion, advanced by so high an authority, demands our attentive consideration.

Ammonia has been detected in many clays, and traces of it may be discovered in most soils, but it is not known to be a natural or essential constituent of any of the solid rocks of which the crust of the globe is composed. These clays and soils, therefore, may be supposed to have derived their ammonia from the atmosphere; and Liebig ascribes the fertilizing action of the air upon stiff clays when fallowed, of burned clay when applied as a top-dressing, and of gypsum on grass* lands, to the larger quantity of ammonia which the surface of the soil is by these means caused to absorb and retain.

There is no question that ammonia is present in the atmosphere in small and variable quantity (p. 45). Whence is this ammonia derived, and is its quantity sufficient to supply the demands of the entire vegetation of the globe?

When animal substances undergo decay, nearly all the nitrogen they contain is ultimately separated from the other constituents in the form of ammonia. During the decay of plants also, a portion of their nitrogen escapes in the state of ammonia. Of the ammonia thus formed, much ascends into the air, chiefly in combination with carbonic acid as carbonate of ammonia (smelling salts), and much remains in the soil. Were the whole of the nitrogen contained in plants and animals to assume the form of ammonia when they decay, and to remain in the soil or in the air, it would always be within the reach either of the roots or leaves of the living races; and thus the same ammonia* might again and again return into the circulation of new vegetable tribes, and be always alone sufficient to supply all the demands of the existing vegetation of the globe.

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* See note to page 70.

But of the ammonia thus formed, a portion is daily washed from the soil by the rains and carried to the sea, and much more probably is washed from the air by the waters of the sea itself, or by the rains which fall directly into the wide oceans; and we know of no compensating process by which this ammonia can be restored to the air, and again made useful to vegetation.

Besides, of that which still remains in the air much must undergo decomposition by natural processes. In treating in a preceding section of the evolution of light carburetted hydrogen during the slow decay of vegetable matter (p. 228), I have shown how, in consequence of its admixture with the oxygen of the atmosphere, this gas is finally decomposed, while carbonic acid and water are produced. Ammonia in like manner will burn in oxygen gas, and when mixed with atmospheric air may be decomposed by the electric spark—water at the same time being formed and nitrogen set free. Thus, if with

1 of AMMONIA = NH^3 we mix
3 of OXYGEN = O^3 we have
3 of water. 1 of nitrogen.
the Sum $NH^3O^3 = 3HO + N$

or, when diffused through the air, 1 of ammonia, with the aid of 3 of oxygen, will yield 3 of watery vapour, while the nitrogen may[*] mingle with the air in an elementary form. Can we doubt that ammonia is thus decomposed in the air? Not to speak of other forms assumed by the electricity of the atmosphere, can the thunder-storms of the tropical regions pass unheeded the ammoniacal vapours they must meet with in their course?

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* Or ammonia containing the same nitrogen—supposing the hydrogen to have been changed.

I conclude, then, that of the ammonia which is formed from the nitrogen actually existing in animal and vegetable substances during their decay, only a *comparatively* small portion ever returns again to minister to the wants of new races.[†]

But if plants obtain all their nitrogen from ammonia,[‡] how is this waste repaired—whence are new supplies constantly derived?

We have seen that, in certain volcanic countries, carbonic acid is evolved in vast quantities from rents and fissures in the earth. In some of these districts—and this has been observed more especially in Italy and Sicily, and it is said also to some extent in China—ammonia is likewise given off, in combination generally with some acid, and most frequently with the muriatic acid in the form of sal-ammoniac (muriate of ammonia). "*This ammonia,*" Liebig is correct in saying, "*has not been produced by the animal organism;*" but he assumes a very doubtful position when he adds, "*it existed before the creation of human beings; it is a part, a primary constituent of the globe itself.*"[§]

Where, we might ask, has this ammonia existed during all past time—from what deep caverns of the earth does it now escape?

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[*] I say *may*, because it may at the same time combine with oxygen and form nitric acid.—See the following section, p. 239.

[†] I might add, that of the ammonia which does return, and is again absorbed, a portion is subsequently decomposed in the interior of living plants, as is shown by the evolution of nitrogen from the common leaves of some and the flower leaves of others.

[‡] "Wild plants obtain *more nitrogen from the atmosphere, in the form of ammonia, than they require for their growth,* FOR the water which evaporates through their leaves and blossoms emits, after a time, a putrid smell—a peculiarity possessed only by such bodies as contain nitrogen." Liebig, *Organic Chemistry applied to Agriculture*, p. 85. Does the fact here stated, justify the conclusion which appears to be drawn from it?

[§] *Ibid*, p. 112.

This opinion of Liebig, as well as the paramount influence he ascribes to ammonia over the vegetation of the globe, are based chiefly on the fact that we know of no means by which ammonia can be formed by the *direct* union of the hydrogen and nitrogen of which it consists.

But the production of ammonia, by the *indirect* union of these elements, is daily going on in nature, and can even be effected by different processes of art. Thus—

1°. When organic substances, which contain no nitrogen, are oxidized in the air, ammonia is not unfrequently formed (Berzelius). Hence it must be produced in unknown quantity during the annual decay of all vegetable substances.

2°. When inorganic substances are oxidized in the presence of air and water—as when moist iron filings are exposed to the air (Chevallier), or when certain oxidized substances are decomposed in the air by means of potassium (Faraday), or when metals, such as tin filings, are rapidly oxidized by means of nitric acid, ammonia is also produced in variable quantity. Hence the absorption of oxygen, even by the inorganic substances of the soil, may give rise to the formation of ammonia. But,

4°. The fact which most clearly illustrates the production of ammonia in nature, both on the surface of the earth in the soil, and far in the interior near the seat of volcanic fires, is this, that if a current of moist air be made to pass over red-hot charcoal, carbonic acid and ammonia are simultaneously formed.* This is in reality only a repetition in another form of what takes place, as above stated, when vegetable matter decays, or iron filings rust in moist air.

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* This experiment is easily performed by *drawing* a current of mixed atmospheric air and steam through a red-hot gun-barrel filled with well-burned charcoal, and causing the current, on leaving the barrel, to pass through water acidulated with muriatic acid. After a time, the water, on evaporation, will be found to contain traces of sal-ammoniac. What thus takes place in a small experiment of this kind must more readily and more largely take place in the interior of the earth, where combustible substances at a high temperature happen to be exposed to a current of atmospheric air, mixed with watery vapour.

The carbon and the iron decompose the watery vapour in the air, and combine with its oxygen, while, at the instant* of its liberation, the hydrogen of the water combines with the nitrogen of the air, and forms ammonia.

The source of the ammonia evolved in volcanic districts, therefore, is no longer obscure. The existence of combustible matter in such districts, and at great depths beneath the surface, can in few cases be doubted, and the passage of a mixed atmosphere of common air and steam over such combustible matter, at a high temperature, appears to be alone necessary to the production of ammonia. It is unnecessary, then, to have recourse to doubtful speculations in order to account for the natural reproduction of ammonia, to a certain extent, in the place of that which is constantly undergoing decomposition by the agency of causes such as those above described.

But is the indefinite quantity of ammonia reproduced by these indirect methods sufficient to replace *all* that is lost? Can it be supposed to impart to plants all the nitrogen they require? These questions will be considered in the following section.

§ 5. *Of the supply of nitric acid to plants.*

In regard to the action of nitric acid upon vegetation it is known—

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* A beautiful illustration of the tendency which elementary substances have to unite with each other at the *instant* of their liberation in what chemists call their *nascent* state, is mentioned by Runge.—*Einleitung in die technische Chemie*, p. 373.

If 1 part of hydrate of potash and 20 of iron filings be heated together, *hydrogen only is given off.*

If 1 of nitrate of potash and 20 of iron filings be heated together, *nitrogen only is given off.*

But if 40 of iron filings be mixed with 1 of hydrate and 1 of nitrate of potash, and then heated, *ammonia becomes perceptible.*

The nitrogen and hydrogen being given off together, and at the same instant, some portions of each find themselves in a condition to unite, and thus ammonia is produced. The same result must follow in many natural operations, when hydrogen and nitrogen are set free from a previous state of combination, at the same time, and in the presence of one another.

1°. That when, in the form of nitrates of soda, potash, &c., it is spread upon the soil, it greatly promotes the growth and luxuriance of the crop and increases its produce; and

2°. That, when other circumstances are favourable to vegetation—as in certain districts in India—the presence of an appreciable quantity of these nitrates adds largely to the fertility of the soil.*

The same effects are unquestionably produced by the addition of ammonia or by its natural presence in the soil. The beneficial influence of both compounds, then, being recognized, the relative extent to which each operates upon the general vegetation of the globe will be mainly determined by the circumstances and the quantity in which they respectively exist or are reproduced.

In regard to the existence of nitric acid, it is not known to form a necessary constituent of any of the solid rocks of which the crust of the globe is composed, but is diffused almost universally through the soil which overspreads the surface. In the hotter regions of the earth, in India, in Africa, and in South America (p. 76), it in many places accumulates in sufficient quantity to form incrustations of considerable thickness over very large areas, and in many more it can be separated by washing the soil. Even in the climates of Northern Europe, it is rarely absent from the water of artificial wells, into which the rains, after filtering through the surface, are permitted to make their way.*

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* For the following, and other interesting notices, regarding Indian agriculture, I am indebted to Mr. Fleming, of Barochan, in Renfrewshire, whose long residence in the districts to which he alludes, as well as the interest he takes in practical agriculture, renders his testimony very valuable:

"The districts of Chaprah, Tirhoot, and Shahabad, near Patna, where a large proportion of the saltpetre sent from Bengal is produced, are considered the most fertile in Bengal, producing 2 and sometimes 3 crops yearly. The natives of these districts, particularly a caste called Quirees (hereditary gardeners), who cultivate the best land, and produce the best crops, are in the habit of irrigating their fields with water from wells so strongly impregnated with saltpetre and other salts as to be quite brackish, and they consider onions, turnips, and peas, most benefitted by this irrigation. Grain crops also grow most luxuriantly on lands yielding saltpetre, where there is enough of rain within a week or two after the seed is sown, but if a drought follows the sowing, and continues for 3 weeks or a month, the leaf becomes yellow, and the crop fails.

"The Hindoos do not generally manure their lands, as the dung of the cattle is used for fuel, but the Quirees collect the ashes of cow dung and of burned wood, and use it as a manure in some cases, chiefly for the poppy plant.

"The Hindoos have for ages been well acquainted with the rotation of crops, and the advantages of fallowing land, although a great proportion of the land is almost constantly in rice, Indian corn, or millet, during the rainy season, and in wheat or peas during the dry season."

On the whole, nitric acid and its compounds, appear to *exist*, ready formed in nature, in larger quantity than either ammonia or any of its compounds.

Of these nitrates, as they do of ammonia, the rivers must be continually bearing a portion to the sea, but there are in nature unceasing processes of reproduction, by which not only this waste of the nitrates is repaired, but that further waste, also, which is caused by their absorption into the roots and subsequent decomposition in the interior of plants. Let us shortly consider these processes of reproduction.

1°. When a succession of electric sparks is passed through common air, nitric acid (NO^5), is slowly but sensibly formed. The currents of electricity which in nature traverse the atmosphere must produce the same effect, and the passage of each flash of lightning through the air must be attended by the formation of some portion of this acid.

After a thunder storm plants appear wonderfully refreshed; in thundery weather they grow most luxuriantly, and other things being equal, those seasons in which there is much thunder are observed to be the most fruitful. Some have ascribed these results to the *immediate* agency of electricity on the growth of plants.† Is it not equally possible that they may be connected with this necessary production of nitric acid?

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* It occurs in the wells of the neighbourhood of Berlin (Mitscherlich), in the form of nitrates of potash, lime, and magnesia, in the wells around Stockholm, and may be expected in all wells that are dug (Berzelius).—*Traité de Chemie*, iv., p. 71.

† Sprengel, *Chemie I.*, p. 99.

In the rain which fell during 17 thunder storms, Liebig found nitric acid always present and generally in combination with lime and ammonia. In the rain which fell on 60 other occasions, he could detect it only twice. In minute quantity nitric acid is difficult to detect. How much then must be formed in a thunder storm, even in our climate, to make the presence of this acid *always* appreciable in the rain that falls—how vast a quantity in those warmer climates where such storms are so frequent and so appalling!

2°. When a mixture of ammonia with oxygen gas is exploded by passing an electric spark through it, a quantity of nitric acid is formed, even when the oxygen is not sufficient to oxidize the whole of the ammonia* (Bischof). Hence, if in the air, as we have seen reason to believe, the ammonia given off from decaying animal matters, and from other sources, be decomposed by the atmospheric electricity,—there will necessarily be formed at the same instant a portion of nitric acid, at the expense of the nitrogen of the ammonia itself. This nitric acid will, as necessarily, combine with some of the ammonia which still remains in the air. Hence the existence and production of *nitrate of ammonia* in the atmosphere, and the consequent presence of this acid along with ammonia in rain water.

Thus the very cause which in the preceding section was shewn to operate in constantly diminishing the amount of ammonia in the air, and the operation of which certainly renders improbable the existence of this compound in the atmosphere in the large quantity supposed by some†—this same cause is at the same moment constantly reproducing nitric acid. And, though much of what is thus produced must necessarily, as in the case of ammonia, be carried down to the sea by the rains, or be directly absorbed by the waters of the ocean themselves, yet it is obvious that in whatever proportion we may suppose the ammonia of the air to reach the leaves and roots of plants, in no less proportion must the nitric acid, with which it is associated, be enabled to enter into the circulating system of the various tribes of living vegetables, that flourish on every quarter of the globe.

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* It was shewn above (p. 234), that 1 of ammonia NH^3 requires 3 of oxygen to decompose it, forming 3 of water, and setting the nitrogen free. But, in reality, as Bischof has shewn, the nitrogen is not wholly set free, but a portion both of its hydrogen and nitrogen combine with oxygen (are oxidized) at the same instant, forming simultaneously both water (HO), and nitric acid (NO^5).

† See especially Liebig's *Organic Chemistry applied to Agriculture*, p. 74.

3°. Again we have seen that, during the decay of vegetable substances in moist air, ammonia is formed at the expense of the hydrogen of the water and of the nitrogen of the air. In consequence of, or in connection with, such decay, nitric acid is also largely produced in nature.

The most familiar, as well as the most instructive examples of this formation of nitric acid is in the artificial nitre-beds of France and the North of Europe. These are formed by mixing earth of different kinds with stable manure or other animal and vegetable matters, and exposing the mixture to the air in long ridges or conical heaps, which are occasionally watered with liquid manure, and turned over, to expose fresh portions to the air. After a time, perhaps once a year, the whole is washed, when the water which comes off is found to contain a variable quantity of the nitrates of potash, soda, lime, and magnesia, which are employed for the manufacture of saltpetre. In these nitre beds it has been observed that the production of nitric acid either does not take place at all, or only with extreme slowness, unless animal and vegetable matter be present in considerable proportion. And yet the quantity of nitric acid which is formed is much greater than could be produced by the oxidation of the whole of the nitrogen contained in the organic matters present in the mixture.* It is also observed that the nitre-beds are more productive when a portion from one outer face of the heap is lixiviated from time to time, and the washed earth added to the other side, than when the whole is lixiviated at once, and again formed into a heap and exposed to the air.

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* Dumas, *Traité de Chemie II.*, p. 725. He adds, that 100 lbs. of nitre contain the nitrogen of 75 lbs. of ordinary animal matter, supposed in a dry state, or of 300 or 400 lbs. in its ordinary state of moisture,—a much greater relative proportion of animal matter than is ever added to the heap.

It appears, therefore, that organic matters are in our climate necessary to cause the formation of nitric acid to *commence*, but that after it has begun it will proceed in the same heap for an indefinite period, and at the expense apparently of the *nitrogen of the air only.*

Compost heaps are in general only artificial nitre-beds, often unskilfully prepared and badly managed, producing, however, a certain quantity of nitrates, to the presence of which their effect on vegetation may not unfrequently be ascribed. To this fact we shall hereafter recur.

The soils in the plains of India, and in other similar spots in the tropical regions, may be regarded as *natural* nitre-beds, in which, the decay of organic matter being vastly more rapid than in our temperate regions, the production of nitric acid is rapid in proportion.*

4°. But in many localities in which the presence of organic matter is not to be recognised in sensible quantity, the production of this acid is observed to proceed with a constant and steady pace. Thus, from the walls of certain caves in Ceylon a layer is yearly pared off, which yields an abundant crop of saltpetre (Dr. John Davy). The celebrated Mammoth cave in Kentucky, situated in a limestone ridge, yields an inexhaustible supply of nitrate of lime. During the war with Great Britain, fifty men were constantly employed in lixiviating the earth of this cave, and in about three years the washed earth is said to become as strongly impregnated as at first. Through the cave a strong current of air is continually rushing—inwards in winter and outwards during the summer months. On the plaster of old walls, especially in damp situations, an efflorescence of this and other nitrates is frequently observed over every part of Europe. In China, according to Davis, the old plaster of the houses is so much esteemed as a manure, that parties will often purchase it at the expense of a coating of new plaster. Old clay walls, and especially the walls of clay-built huts, are said to be very fertilizing to the land, when applied as a top-dressing, and in some parts of England, where the land is poor, the people are said to pile up the soil in the form of walls, in order to improve its quality. These latter facts seem to indicate that both in China and England nitric acid is produced in similar circumstances, and that to its production the fertilizing action of the old plaster, and of the *weathered* clay, is alike to be attributed.

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* We are as yet too little acquainted with the natural history of the district of Arica in South America, in which, as already stated (p. 76), the nitrate of soda has been accumulated in such large quantity, to be able to say to what *special* cause the accumulation is due. But as, from the description of Mr. Darwin, the locality appears to have been the site of an ancient lake, it is not unlikely that the nitrate may have been derived from the successive washings of a soil similar to that of India, by rains or periodical floods, which for a long period emptied themselves into or fed the lake.

In the cultivated soil also, this acid is formed in ordinary circumstances. Braconnot found nitrate of potash in the botanic garden at Nancy, in a portion of soil in which poppies (*papaver somniferum*) had grown luxuriantly for ten years in succession—in larger quantity in the soil surrounding the interlaced roots of an *esclepias incarnata*, growing in an ordinary flower-pot, with a hole in the bottom—as well as in moss earth, in which a plant of *euphorbia breoni* had been grown in a pot.* There is little reason to doubt, indeed, that nitrates are to be found, in greater or less quantity, in all cultivated soils.

I shall not enter into a detailed inquiry how this nitric acid is formed. It is probable that as in the atmosphere ammonia may be decomposed and give rise to the formation of nitric acid, so in the soil this acid may result from a similar decomposition, proceeding more slowly, but according to the same natural laws. In warm climates, indeed, it appears certain that the ammonia which is evolved or formed during the decay of animal and vegetable substances, does speedily, and to a great extent, undergo oxidation,† and thus give rise

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* *An. de Chim. et de Phys.*, lxxii., p. 33 to 35.

† For the perfect oxidation of 1 of ammonia, no less than 8 of oxygen are required. Thus

$$\overset{\text{1 of Ammonia.}}{NH^3} + 8O = \overset{\text{1 of Nitric Acid.}}{NO^5} + \overset{\text{3 of Water.}}{3HO}$$

to the greater abundance of nitric acid with which the tropical soils abound.

Thus, in the economy of nature, much ammonia is decomposed in the soil also, and hence another cause for the constant diminution of the quantity of this compound in addition to those already detailed in the preceding section.

But, besides the portion of this nitric acid, which owes its existence to the decomposition of ammonia, much, by far the greatest proportion in all probability, derives its origin from the union of the elements of the atmosphere itself. This direct union is effected in the *air*, as has been already shown, by the agency of atmospheric electricity; but it also takes place in the *soil* during the oxidation of the other elements contained in the organic matters which are there undergoing decay. The combination of the elements of ammonia in such circumstances proceeds on the principle that bodies, themselves undergoing oxidation, *dispose* other substances in contact with them (in this instance the nitrogen of the air) to unite with oxygen also. The presence of lime, potash, &c. in the soil, further induces to this oxidation by the tendency of these substances to combine with the acid which is formed by this union of the elements of which nitric acid consists.

It is impossible precisely to estimate the quantity of nitric acid produced in these various ways, through these various agents, and in these varied circumstances, or to balance it *accurately* against the amount of ammonia continually reproduced, as we have seen, in nature, wherever the necessary conditions present themselves. But, as I formerly concluded, that the amount of nitric acid actually existing in the superficial deposits of our globe is greater than that of ammonia, so I think that, in regard to the reproduction also of these two compounds, the balance is in favour of the former.

Since, then, nitric acid is fitted, by the solubility of its compounds, to enter into the circulation of plants in any quantity—since, when applied to them, it does undoubtedly promote, in a remarkable degree, the growth of plants—and since, in nature, it is continually reproduced in every country, and under such varied circumstances—I cannot with-hold myself from the conclusion, that, over the general vegetation of the globe, it holds with ammonia at least an equal sway, and is appointed to exercise at least an equal influence over the growth of plants, both in their natural and in their cultivated state.

Still the influence of each is not unvaried by locality or by climate. The extent of dominion exercised by the nitrates probably diminishes as we recede from the equator, while that of ammonia increases,—it may be in an equal proportion. The reason of this probable variation will appear in the following section.

§ 6. *Theory of the action of nitric acid and ammonia.*

These two compounds act so far in common as to yield a supply of nitrogen to the plants into which they enter. They do so, however, under conditions which may be considerably different, and may be attended by unlike chemical changes.

I.—THEORY OF THE ACTION OF NITRIC ACID.

1°. The nitric acid of the nitrates entering into the circulation of the roots will ascend to the leaf, and will there be decomposed in the same way as the carbonic and other similar acids are, by the action of the sun's rays. It is only in the light of day that carbonic acid is decomposed in the green parts of plants—so must it be, generally, with the nitric acid which ascends to the leaf. Its oxygen will be given off, while its nitrogen may be retained in the circulating system of the plant. The extent to which this decomposition will take place at each passage of the sap through the leaf will depend, in some degree, on the nature of the base (whether potash, soda, or lime) with which the acid is in combination, but much more on the intensity of the light to which the green parts of the plant are exposed, and on the temperature of the air in which the plant happens to grow.

2°. It is still uncertain whether this acid is capable of being decomposed in the roots or stems of plants where it is excluded from the light, though it is very probable that it may be so, especially in cases where the juices naturally contain substances in which hydrogen is present in excess, or where such compounds make their way into the circulation of plants from the manure that may be applied to their roots.

Thus in the pines, in which turpentine ($C^{40}\ H^{32}$) naturally abounds, such a decomposition may the more readily occur, inasmuch as it would not necessarily imply the production and evolution of any gaseous substance. Thus

1 of Oil of Turpentine, = $C^{40}\ H^{32}$ with the oxygen of
1 of Nitric Acid ($N\ O^5$,) = O^5 gives

1 of Resin, ... = $C^{40}\ H^{32}\ \ O^5$

By uniting with the oxygen of the nitric acid, therefore, oil of turpentine, in such trees, might be changed into resin during its passage through the stem, while the nitrogen, being set free, might, at the moment of its liberation, unite with other elements to form those parts or productions of the tree, into which this element enters as a necessary constituent.

The above must be considered merely as an illustration of the *kind* of changes which may possibly take place in the interior of certain plants, and in the absence of light, when the nitrates happen to be present. Were I to affirm that such changes actually do occur in the presence of nitric acid, the theoretical chemist would have a right to expect that several collateral questions should be discussed, the consideration of which would here be out of place.

3°. The nitrates may also act in another way, which does not involve the necessity of the total decomposition of the acid they contain. We know that in nature many substances are capable of inducing chemical changes in other compound bodies, without themselves undergoing decomposition. Some beautiful illustrations of this have already been given in a previous lecture, when treating of the action of sulphuric acid upon starch and woody fibre.* But the fact which most immediately bears on the influence of the nitric acid in the living plant, is that mentioned in p. 186,—that by solution in this acid in the cold, starch is converted into a substance having the composition of woody fibre. In the interior of the plant changes of this kind may be produced by simple contact only, with the nitric acid, so that, without being decomposed, it may be materially serviceable in promoting those molecular changes which are necessary to the healthy and rapid growth of the plant.

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* Lecture VI., pp. 165, 167.

II.—THEORY OF THE ACTION OF AMMONIA.

1°. Ammonia is capable of contributing to the growth of the plant, by means of the hydrogen, as well as of the nitrogen it contains. We have seen* that, according to the results of the best experiments, the whole of the oxygen of the carbonic acid absorbed, is not given off by the leaves of all plants even in the sunshine,—while in the dark this gas is largely and directly imbibed from the air. If in the sap of a plant there be present at the same time a quantity of ammonia, the hydrogen of this ammonia may unite directly with the oxygen of the carbonic acid, forming water and a proportionate quantity of one or other of the several compounds (p. 163), which may be represented by carbon and water. Thus

3 of Carbonic Acid, $= C^3 \quad O^6$ and the hydrogen of
2 of Ammonia (NH^3) $= \quad H^6$

¼ of Grape Sugar. 3 of Water.

give . . . . . $C^3 H^6 O^6 = C^3 H^3 O^3 + {}^3 H O$

so that where ammonia is present, and circumstances are favourable, sugar or starch may be formed in variable quantity, without the necessary evolution of oxygen gas. This change will take place in the interior of the leaf. And, if the direct decomposition of carbonic acid, and the evolution of its oxygen by the agency of the sun, take place at the same time—with a rapidity proportioned to the intensity of the light,—this simultaneous production of sugar, &c., from the presence of ammonia, must aid the increase and growth of the plant; and may be one main cause of the fertilizing action of this compound, which has been so long and so generally recognised.

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* Notes to pages 201 and 205.

When the hydrogen of the ammonia is thus worked up, the quantity of oxygen which escapes from the leaf must be less in proportion; and hence another cause (p. 205) for those discrepancies which have been observed in regard to the bulk of oxygen given off, compared with that of the carbonic acid taken in, by the leaves of different plants.

But at the same time the nitrogen is set free. This nitrogen will either be again compounded in the plant with other elements, or, if not required for its healthy growth—that is, if more largely present than is required by the plant—it will be directly emitted by the leaves, or sent downwards and permitted to escape by the root. Hence the reason why pure nitrogen is evolved from the leaves of some plants (p. 137), and why ammonia exercises a beneficial action upon vegetation, in cases where all the nitrogen it contains is neither retained nor required by the plant.

Does this decomposition necessarily require the agency of light? May it not take place in the absence of the sun?

I will mention one or two facts which seem to throw light upon this point.

1°. Plants grow in the dark. Though feeble and blanched they increase largely in bulk; they must, therefore, have the power of assimilating their food to a certain extent, *independent of the sun's rays.*

2°. Several species of Poa, Plantago, Trifolium arvense, Cheiranthus, &c., become green in the perpetual darkness of mines (Humboldt.)

3°. When a little hydrogen is mixed with the air, plants become greenish, even in the dark (Sennebier); and when exposed to the sun, the green becomes unusually intense in such a mixture (Ingenhouss).

The immediate and visible effect of an application of ammonia, or of soot, or of any top dressing containing ammonia, is to render the green colour much more intense, and in the darkest weather. It is therefore probable, I think, that the hydrogen of the ammonia contributes to this immediate effect, and that the ammonia itself may be decomposed and its elements appropriated to the nourishment of the living vegetable, either by the unaided vital powers of the plant, or in the presence of a feeble light only. Like water, ammonia is *peculiarly* liable to decomposition, not always of that perfect kind which, *for the sake of simplicity*, I have endeavoured to explain in the present lecture, yet such as to render the elements of which it consists available to the general nourishment of the plant.

§ 7. *Comparative influence of nitric acid and of ammonia in different climates.*

It follows, from what is above stated, that the beneficial influence of ammonia upon vegetation will be readily perceived in all climates in which plants are found to flourish. Its effects will be greater and more rapid where the heat and light are more intense,—only because by these agents the functions of all life are stimulated.

Not so with the nitric acid in the nitrates. In the presence of organic compounds, that is, in the sap of the plant, it is less easily decomposed than ammonia. It requires the interference of more powerful agents—of a higher temperature, or of more brilliant light,—and thus its efficacy upon vegetation will be more dependent upon season and climate.

Now, we have seen that in tropical countries the nitrates are produced in the greatest abundance, and there the high temperature and the brilliant sun should render them most useful to vegetation. Such is well known to be the case, and it may be regarded as one of those bountiful adaptations with which all nature is full—that in these warmer regions, the ammonia produced in the soil is first converted into nitric acid, that it may *remain fixed*, and that this acid again is decomposed by the same agents (light and heat), when it enters the living plant, and is required to minister to its growth. On the other hand, it may no less be regarded as a wise provision, that in colder and more uncertain climates, where warm and brilliant summers are less to be depended upon, that compound of nitrogen (ammonia) should more abound, which is most easily decomposed in the living plant, which is fitted in comparative darkness to yield up its nitrogen, and by the hydrogen it contains, to compensate in some slight degree for the partial absence of the sun's rays.

From these views, therefore, we should draw this further practical conclusion—that in our climate, ammonia is sure to promote vegetation, and in every season, while the nitrates will produce their *maximum* effect, other things being equal, in such only as have abundant warmth and sunshine. Is this conclusion consistent with observation? Will it serve to explain any of the apparent failures which have occasionally been experienced in the employment of the nitrates?

§ 8. *Stimulating influence of these compounds.*

There remains one other point in regard to the effect of these two compounds upon vegetation, to which I would request your attention. We have seen that the quantity of nitrogen contained in a crop raised by the aid of farm-yard manure, is very much greater than that which exists in the manure itself, and the views just exposed serve to indicate the sources from which the excess is derived. But suppose that upon two patches of ground, of equal quality, the one of which is manured and the other not, equal quantities of the same seed be sown, it is consistent with experience—that the crop reaped from the manured portion will not only contain more nitrogen than that reaped from the unmanured portion, but so much more as shall considerably exceed that contained in the manure also. Thus suppose the crop raised from the unmanured land to contain 100 lbs. of nitrogen, and that the manure laid on the other portion contained 100 lbs. also, the crop which is reaped from this latter portion, in favourable seasons, will exceed, and probably very far exceed, 200 lbs. Hence the effect of the ammonia, &c., in the farm-yard manure, is not merely to yield its own nitrogen to the plant, but to enable it, in some way hitherto unexplained, to draw from other sources a larger portion of the same element than it would otherwise do.

So also with the nitrates. If two equal portions of the same grass or corn-field, in early spring, be measured off, and one of them be top-dressed with nitrate of soda or with saltpetre, the weight of nitrogen contained in the crop of hay or corn reaped from the latter, will generally be found to exceed that contained in the crop from the former, by a quantity much greater than that which was present in the nitrate with which the land was dressed.* In addition, therefore, to the nitrogen directly conveyed to the plant by these nitrates, they also exercise some other influence, by which they enable the living vegetable to draw from natural

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* The following calculations illustrate the statement in the text:—Mr. Gray, of Dilston,* applied nitrate of soda to grass land in the proportion of 112 lbs. to the acre.

The produce without nitrate amounted to	2 tons	81 stones
" " with 112 lbs. of nitrate to	3 tons	146 stones
Increase,	1 ton	65 stones
	or 3150	lbs.

And 3150 ÷ 112 = 28⅛ lbs. the increase of hay from each pound of nitrate of soda.† But allowing this hay to contain only one per cent. of nitrogen, 28 lbs. will contain 4½ ounces of nitrogen, which is nearly double the quantity actually present in the nitrate employed.

Again, in the case of a crop of grain—Mr. Hyett applied nitrate of soda to a field of wheat, and compared the produce with that from an equal portion to which no top-dressing was applied.

	CORN.			STRAW.		
	Bush.	pks.	pts.	Cwt.	qrs.	lbs.
Nitrated . .	43	2	11	31	2	3
Without nitrate	33	2	6	23	1	21
Excess,	10	0	5	8	0	10

Calculating the bushel of corn at 60 lbs., the excess of corn amounted to 600 lbs., containing 24½ per cent. or 147 lbs. of gluten and albumen. The nitrogen in these substances, when properly dried, is from 15 to 17 per cent. If we suppose the gluten not to have been quite dry, and allow only 14 per cent. of nitrogen, 147 lbs. would contain 20½ lbs. of this element.

But the nitrated corn contained 5 per cent. more gluten and albumen

[* See Journal of Royal English Agricultural Society.]

[† Dry nitrate of soda contains about 16½ per cent of nitrogen, being 19 lbs. to the cwt., or two and three-fifth ounces to the pound; but as it is usually applied, it contains from 5 to 10 per cent. of water. The nitrogen, therefore, may be estimated at 2½ ounces in the pound.]

sources a much larger supply than they would otherwise be capable of doing. What is this influence, and how is it explained?

This I suppose to be that kind of influence to which writers on agriculture are in the habit of alluding, when they speak of certain substances *stimulating* plants, or acting as *stimulants* to their growth, though the term itself conveys to the mind no distinct idea of the mode of operation intended to be indicated—of the way in which the effect is produced.

In the present case, this special action of ammonia and the nitrates, and perhaps also of immediate applications of manure in general, appears to arise from their affording to the plant, in its early youth, a copious supply of nitrogenous food, by which it is enabled at once to shoot out in a more healthy and vigorous manner. It thrusts forth roots in greater numbers, and to greater distances, and is thus enabled to extract nourishment from a greater extent and depth of soil than is ever reached by the sickly plant—it expands larger and more numerous leaves, and thus can extract from the air more of every thing it contains which

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than the un-nitrated, which in 33 bushels (2000 lbs.) gives 100 lbs. of gluten in excess, containing 14 lbs. of nitrogen.

And 8 cwt. of straw (900 lbs.) contained one-third of a per cent. of nitrogen*, or in all 3 lbs.

Therefore the quantity of nitrogen present in the nitrated crop above that in the un-nitrated was as follows:

	Nitrogen.
1°. In 600 lbs. of wheat at 24½ per cent. of gluten .	20½ lbs.
2°. In 2000 lbs. of wheat at 5 per cent. of gluten contained in excess	14 lbs.
3°. In 900 lbs. of straw at one-third per cent. . .	3 lbs.
Total nitrogen .	= 37½ lbs.

But the nitrogen in 1 cwt. of dry nitrate of soda, as already stated, is only 19 lbs. or little more than half the quantity, which in consequence of the presence and action of the nitrate the wheat was enabled to obtain and appropriate above the quantity appropriated by the wheat in the un-nitrated part of the field.

It requires no further proof, therefore, to show that *the nitrate of soda and the nitrates must act in some other way in reference to vegetation, than by simply supplying a portion of nitrogen.*

[* Boussingault.]

is fitted to supply the wants of the living vegetable; as the stout and healthy savage can hunt and fish to support many lives, while the feeble or sickly can scarcely secure sustenance for himself alone. Feed a wild animal well the the first few months of its life, and you may set it loose to prey for itself; starve it in its infancy, and its growth and strength will be stunted, and it may lead a wretched and hungry life.

Even in soils, then, and situations, which are capable of yielding to the plant every thing it may require for its ordinary growth, it is an important object of the art of husbandry to discover what substances are especially *necessary* or grateful to particular crops, and to apply *these directly, and in abundance*, to the new-born plant,—in order that it may acquire sufficient strength to be able to avail itself in the greatest degree of the stores of food which lie within its reach.

Concluding observations regarding the organic constituents of plants.

We have now considered the most important of those questions connected with the organic elements of plants, which are directly interesting to the practical agriculturist. We have seen—

1°. That all vegetable productions consist of two parts—one, the organic part, which is capable of being burned away in the air—the other, the inorganic part, which remains behind in the form of ash.

2°. That this organic part consists of carbon, hydrogen, oxygen, and nitrogen only.

3°. That plants derive the greater part of their carbon from carbonic acid, of their hydrogen and oxygen from water, and of their nitrogen from ammonia and nitric acid.

4°. That by far the largest portion of those substances which form the principal mass of plants, such as starch and woody fibre, consists of carbon united to oxygen and hydrogen in the proportions in which they exist in water,—or, in other words, may be represented by carbon and water in various proportions.

5°. That the food on which they live enters by the roots and leaves of plants,—that the leaves, under the influence of the sun, decompose the carbonic acid, give off its oxygen, and retain its carbon,—and that this carbon, uniting with the elements of water in the sap, forms those several compounds of which plants chiefly consist.

6°. That the supply of carbonic acid in the atmosphere is kept up partly by the respiration of animals, partly by the natural decay of dead vegetable matter, and partly by combustion. That ammonia is supplied to plants chiefly by the natural decay of animal and vegetable substances—and nitric acid partly by the natural oxidation of dead organic matter, and partly by the direct union of oxygen and nitrogen, through the agency of the atmospheric electricity.

7°. That while both of these compounds yield nitrogen to plants, they each exhibit a special action on vegetable life, in virtue of the hydrogen and oxygen they respectively contain—and exercise also a so-called *stimulating* power, by which plants are induced or enabled to appropriate to themselves, from other natural sources, a larger portion of all their constituent elements than they could otherwise obtain or assimilate.

In illustrating these several points, it has been necessary to enter occasionally into details which, to those who have heard or may read only the later lectures, may not be altogether intelligible. I am not aware, however, of having introduced any thing of which the full sense will not appear on a reference to the statements by which it is preceded.

We are now to consider the *inorganic* constituents of plants,—their nature,—the source (the soil) from which they are derived,—their uses in the vegetable and animal economy,—how the supply of these substances is kept up in nature,—and how, in practical husbandry, the want of them may be at once *efficaciously and economically supplied by art*. This division of our subject, though requiring a previous knowledge of the principles discussed in the foregoing lectures, will be more essentially of a practical nature, and will lead us to consider and illustrate the great leading principle by which the practical agriculturist ought to be guided in the cultivation and improvement of his land.

We shall here also find much light thrown upon our path by the results of geological inquiry; and it is in the considerations I am now about to bring before you, that I shall have to direct your attention most especially to the principal applications of Geology to Agriculture.

APPENDIX.

No. I.

SUGGESTIONS FOR EXPERIMENTS IN PRACTICAL AGRICULTURE DURING THE ENSUING SPRING AND SUMMER.

ONE of the most important objects which chemistry is at present desirous of attaining for the improvement of practical agriculture, is the discovery and application of specific or *special* manures.

We know that certain substances, such as fold-yard manure, are capable of fertilizing to a considerable extent almost any land, and of causing it to yield a better return of almost any crop. But we know also that manures or fertilizers of nearly every kind are more efficacious on one soil than on another, and that some answer better also for one species of crop than for another. The case of gypsum will serve to illustrate both these positions.

The effects of gypsum in the United States, in Prussia, and other parts of Germany, and in some districts of England, are said to be absolutely astonishing; while in many other parts of our Island, of Germany, and even of the United States, the benefit derived from it has not repaid the trouble and expense incurred in applying it. Gypsum, therefore, is *specially adapted* for use in certain soils only.

Again, the remarkable effects of gypsum have been observed most distinctly on clover* and certain kinds of grass. The same benefits have not followed, to any thing like an equal extent, from its use on barley, oats, wheat, or other kind of grain. Therefore, while specially adapted to certain soils, it is also specially adapted to certain crops. It is a kind of specific manure for clover and some of the grasses.

Now, neither of these subjects which it is so important to investigate,—neither that of the manures which are especially fitted for each soil, nor of those which are specially fitted for each crop, —can be determined either from theory or from experiments devised and executed in the laboratory of a chemist. The aid of the practical farmer, of many practical farmers, must be called in. Numerous experiments, or trials, must be made in various localities, and by different individuals,—all, however, according to the same rigorous and accurate method,—in order that, from the comparison of many results, something like a general principle may be deduced.

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* In regard to its use in Germany, Lampadius says,—"It may, with certainty, be stated, that by the use of gypsum the produce of clover and the consequent amount of live stock have been increased *at least one-third.*"—DIE LEHRE VON DEN MINERALISCHEN DUNGMITTELN, p. 34.

It is partly with a view to determine the mode of action of certain fertilizers, and partly in the hope of obtaining some additional light on the subject of manures *specifically adapted to particular crops*, that I venture to suggest to you the propriety of making one or more of the following sets of experiments, during the spring and summer of the present year. I could have much enlarged the list of suggestions, but I neither wish to fatigue your attention, nor to place before you more work of the kind than can be readily accomplished, *with little expense* of time, labour, or money. Another season will, I hope, afford us an opportunity of interrogating nature by further, and perhaps more refined, modes of experimenting.

I. *Of Grass and Clover.*

1°. It is beyond dispute, that on certain soils, gypsum causes a largely increased growth of grass and clover, but experiment alone appears capable of determining on *what* soils it is likely to be thus beneficial. Such experiments, therefore, ought to be made on every farm, on a small scale at first, and at little cost,* but made with care and accuracy, and with a minute attention to weights and measures.

2°. The action of gypsum appears to be entirely chemical, but the only explanation of this action yet attempted is far from being satisfactory. It is desirable, therefore, that experiments with other substances should be made, which are likely to throw light on the theory. Important practical results may at the same time be obtained—they are sure, indeed, to follow from a right understanding of the theory.

In the neighbourhood of Lyons, it has been found that very dilute sulphuric acid† (oil of vitriol) exhibits the same beneficial effect upon clover, that has elsewhere attended the use of gypsum.

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* The price of gypsum in London is about 2s. 6d. per cwt.; in Newcastle, 3s.

† Gypsum consists of *sulphuric acid* and *lime*.

It is desirable, therefore, that a comparative experiment should be made with this acid on a portion of the same field to which the gypsum is applied. Where the one fails the other may act.

3°. It was observed by Dr. Home, of Edinburgh, so early as the year 1756, that sulphate of soda[*] had a remarkable effect in promoting the growth of plants—its action being nearly equal to that of saltpetre or nitrate of soda. This fact, though mentioned by Lord Dundonald, has been lost sight of by practical men, the sulphate of soda being generally represented as too high in price to be available as a fertilizer.[†] The use of saltpetre, however, and of nitrate of soda, both of which are more than double the price of sulphate of soda, show that the cost of this latter article ought not to stand in the way of an accurate trial of its value as a fertilizer on various crops. Dry sulphate of soda can be readily obtained from any of the alkali works on the Tyne,[‡] and being an article of domestic manufacture, it is proper that its merits should be ascertained, and, if it can be made available, that its use should be encouraged.

From the circumstance of its containing sulphuric acid, therefore, I would recommend that it should be tried on clover and grass, in comparison with gypsum and sulphuric acid, and on a portion of the same field. It may succeed where the others fail.

4°. Nitrate of soda also, as a top-dressing on grass land, has been often used with great benefit. I have seen grass land in Dumfriesshire, which, after being long let for pasture at 30s. an acre, had been sprinkled with an annual top-dressing of nitrate of soda at the rate of 20s. an acre, and had since readily let at £4 an acre, yielding thus an annual profit of 30s. an acre to the landlord.

In other districts, again, it has been found to answer better for corn. Thus, after a discussion on this subject in the Gloucester Farmers' Club, it was agreed, that nitrate of soda "was a very valuable manure for white straw crops, but when applied to green crops the benefit was not sufficiently great to counter-balance the expense." In Northumberland, where it has been tried in a skilful manner by Mr. Gray, of Dilston, it was found to yield a most profitable return on both hay and barley.

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[*] *Glauber salts*—consisting of sulphuric acid and soda.

[†] Lord Dundonald says—"From experiments it has been proved to promote vegetation in a very high degree. The high price at present of this article precludes the use of it, but could it be made and sold at a cheap rate, it would prove a most valuable acquisition to agriculture." Since the time of Lord Dundonald some trials made in Germany have shown it to have a beneficial action on rye, potatoes, and fruit trees.

[‡] Messrs. Allan & Co., of the Heworth Alkali Works, deliver it in Newcastle and the neighbouring towns, at 9s. or 10s. per cwt.

These results show the necessity of further trials, not only for the purpose of illustrating the cause of the beneficial action of this saline substance, but also with the view of arriving at some general rule by which the practical man may be guided in determining on *what fields*, and for *what crops on those fields*, the nitrate of soda may be beneficially applied.

This experiment, like the others above-mentioned, will be much more valuable, if made in such a way that the result can be compared with that obtained by the use of other chemical agents. I would, therefore, propose that in the same field of grass or clover, a portion should be measured off, to be top-dressed with nitrate of soda, that thus not only the *absolute*, but also the *comparative*, weight of the produce may at the same time be ascertained.

5°. There are other trials also, from which this general subject is capable of receiving illustration. The fertilizing power of gypsum has been explained by its supposed action on the ammonia which is presumed to exist in the atmosphere. If this be the true explanation, a substance containing ammonia should act *at least* as energetically. At all events, the action of fold-yard manure and of putrid urine is supposed to depend chiefly on the ammonia they contain or give off. Now, among the substances containing ammonia in large quantity, which in most towns are allowed to run to waste, the ammoniacal liquor of the gas works is one which can easily be obtained, and can be applied in a liquid state at very little cost. It must be previously diluted with water till its taste and smell become scarcely perceptible.

I would propose, therefore, as a further experiment, that along with one or more of the substances above-mentioned, the ammoniacal liquor of the gas works should be also tried, on a measured portion of ground, and, if possible, in the same field.

6°. Soot, as a manure, is supposed to act partly, if not chiefly, in consequence of the ammonia it contains. In Gloucestershire it is applied to potatoes and to wheat, chiefly to the latter, and with great success. In the Wolds of Yorkshire it is also applied largely to the wheat crop, at the rate of about 24 bushels to the acre.* In this county it is frequently used on grass land, to the amount of 20 bushels an acre, and though I am not aware that it is extensively employed upon clover, I am inclined to anticipate that the sulphur it contains,† in addition to the ammonia, would render it useful to this plant. At all events, comparative experiments in the same field with the gypsum and the ammoniacal liquor, are likely to lead to interesting results.

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* The price is from 6*d.* to 1*s.* a bushel. In this county the soot *is said* to be often of an inferior quality, and brings therefore a less price.

† The *gypsum*, I might also say, for much of our soot contains gypsum, the lime being derived chiefly from the sides of the flue.

7°. Common salt, highly recommended as a manure by some, has been as much depreciated by others, and hence, when directly applied, is considered as a doubtful fertilizer by almost all. The obscurity in regard to its use, however, rests chiefly on the quantity which ought to be employed. The result of comparative experiments made in Germany, showed that a very few pounds per acre were sufficient to produce a largely increased return of grass—while in England it has been beneficially applied within the wide limits of from five to twenty bushels per acre, and, when used for cleaning the land in autumn, of thirty bushels an acre.

Among the comparative experiments upon grass and clover here suggested, the effect of salt might also be tried with the prospect of practical benefit. It would give an additional interest to the experiments and supply an additional term of comparison.

The entire series of experiments, therefore, which I would recommend, would occupy eight patches on a clover or grass field, one of which would be left *undressed* for the purpose of comparison. Thus, each plot being *half an acre:*

Gypsum.	Sulphate of Soda.	Ammoniacal Liquor.	
Sulphuric Acid.	Nitrate of Soda.	Common Salt.	Soot.

The ammoniacal liquor and the soot are placed as far as possible from the gypsum and sulphuric acid, that they may not interfere with each other's action. In a large field they might be placed still farther apart, and other trials might be made in one or two of the vacant spaces.

The appearance of each patch should be entered, *with the date*, in an experiment book, at weekly intervals, and the final produce both of hay and of aftermath carefully noted, both as to *weight* and *quality*.

Nor will the experiment be completed when the crop for the year is gathered in; but, where it is possible, two further points should be ascertained,—

1°. The relative feeding or nourishing properties of the produce. To those who rear and fatten cattle, this is a matter of great importance, and it is one which they could easily determine, at least very approximately.

2°. What has been the permanent effect of the several substances on the soil, as indicated by the comparative quantity and quality of the crop obtained from each half acre, on the *succeeding* or during the *two following* years. The result of these further observations may materially modify the conclusion we should draw from the comparative weight and quality of the produce of the first year.

I shall only observe, in conclusion, on this head, that the result of a simultaneous trial of all these substances in the same field would not only throw much light on the specific action of each on the grass or clover in general, but would be of permanent utility to that farm or locality in which the experiments were made. It would indicate the kind of fertilizer which was best adapted to the farm or neighbourhood, in the existing condition of its general culture. It would form a local record, useful not only to the tenant who made the experiment (if well made) and by whom the farm at the time was tenanted, but more useful by far, and more permanently so, to the owner of the land, whose interest in it is supposed to be not only greater, but much more lasting.

In regard to the *quantities* of the several substances above-mentioned, which are to be applied to each acre, they may probably be varied according to circumstances, but the following may be recommended in the comparative experiments:

1°. Gypsum 2 to 3 cwt. per acre.

2°. Sulphate of Soda 1 cwt. per acre.

3°. Nitrate of Soda 1 cwt. per acre.

4°. Soot 20 bushels per acre—this in different districts may be varied according to the known quality of the soot.

5°. Of Sulphuric Acid from 30 to 40 lbs. per acre, applied at three or four several intervals—and diluted with at least 200 times its weight of water. Or so much water may be added as to make it perfectly tasteless, or so weak as not sensibly to injure the texture of a plant left in it during the previous night.*

6°. Of Ammoniacal Liquor 100 to 200 gallons per acre, according to its strength, for this is constantly varying. It must also be diluted with so large a quantity of water as will render it perfectly tasteless, and is likely to prove most beneficial if laid on at several successive periods.

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* The quantity above-mentioned amounts to about two gallons of the acid of the shops, and it should be diluted with three or four hundred gallons of water.

7°. Of common salt it will be safer to apply not more than four to six bushels an acre; though, where time and circumstances permit, comparative trials might also be made on the efficacy of salt when applied in different proportions, to the *same* land on which the other experiments are made.

As to the *time* when these several dressings ought to be applied, some variation may be made according to the state of the young crop. They need not, in general, be used before the 10th of April, and they should rarely be later than the middle of May.

It will be desirable that in the detail of every set of experiments, the kind and quality of the soil (and subsoil) should be stated—with its drainage and exposure—and the kind of grass or clover which had been sown upon it.

II. *Of Wheat, Barley, and Oats.*

It is known that saltpetre and nitrate of soda produce highly beneficial effects on all these varieties of grain. There remains much to be done, however, before the principle of their operation, or the circumstances on which their most useful application depends, can be clearly understood. Their relative effects on the same kind of grain must be made the subject of more frequent, more precise, and more carefully conducted experiments—and these effects must be compared with those of other fertilizing substances, in order that we may arrive ultimately at some comparative estimate of the practical value of each, in increasing the growth and produce of those crops which are the staples of animal food.

A.—*Of Wheat.*

It is confidently stated by some, as a *general* rule, that saltpetre is more advantageous than nitrate of soda, when applied to wheat. On the other hand, it is beyond question that the aplication of nitrate of soda to wheat has been found productive of remarkable benefit.

Is saltpetre *specially* adapted for wheat of *all varieties*, on *all soils*, and *under every variety of management*, and is nitrate of soda, in like manner, specially fitted for barley and oats?

These are questions to which the experiments hitherto made do not enable us to give a reply. New data must be obtained before we can have the means of reasoning usefully in regard to any of them. I would propose, therefore,—

1°. That where two varieties of wheat are sown on the same field, or on different fields of precisely the same kind of land and in the same condition, that two half acres of each variety should be measured off, and that one half acre of each should be dressed with saltpetre, and the other with nitrate of soda, at the rate of 1 cwt. per acre. If three varieties could be so treated, the experiment would be the more valuable.

It would thus be determined how far the effect of each of these nitrates was dependant upon the *variety* of wheat sown—and what was the relative action of each nitrate upon any of the varieties.

2°. That, when the same varieties of wheat are sown upon two or more different soils—in different parts of a farm—that one portion of the wheat on every different soil should be dressed with nitrate of soda, and another with nitrate of potash (saltpetre). By this experiment, it would be shown how far the effect of these substances is dependant on the nature of the soil, and how far the action of the one, compared with that of the other, is modified by diversity of soil.

In these different experiments, the management is presumed to be the same. If the experiments be repeated by several persons in different parts of the country, the effects of difference of management will, in a great measure, be shown in the diversity of the results.

3°. With the view of ascertaining the comparative effect of the sulphate of soda on this crop, I would suggest that in each case above specified, an equal area should be set aside to be dressed with this salt, in the proportion of 1 cwt. per acre.

Of each variety of wheat, therefore, and on each variety of soil, four patches of equal area, say half an acre, should be measured off—one of which should be undressed for the purpose of comparison: thus—

Nitrate of Soda.	Saltpetre.
	Sulphate of Soda.

As before, the nature of the soil and the kind of grain must be recorded—the appearance of each patch noted week by week—with the time of ripening and reaping—and the respective qualities and weights of the grain and straw collected from each half acre.

The quantity of gluten contained in the wheat should also be determined, or a sample of the flour transmitted for the purpose to the writer of these suggestions, accompanied by a detail of the experiments they are intended to illustrate.

B.—*Of Barley and Oats.*

To barley and oats the above remarks all apply, with this difference, that to these crops saltpetre is said to be less beneficial than the nitrate of soda. In connection with these crops, however, I would make the following additional observation.

According to any theory of the action of the nitrates of potash and soda which readily presents itself, their effect on any crop which they are equally capable of benefitting ought to be nearly equal, weight for weight. The nitrate of soda ought to have a decidedly more powerful action, were it not that the state of moisture in which it is generally sold, increases its weight so much as in a great measure to deprive it, in equal weights, of this superiority.

But while 1 cwt. of saltpetre (nitrate of potash) is recommended as a sufficient dressing for an acre, 1¼ to 1½ cwt. of nitrate of soda is recommended for an equal area. It would, therefore, be desirable where nitrate of soda is applied to any large extent of land, either with oats or barley, to make a comparative trial on three equal portions of the same field, with 1, 1¼ and 1½ cwt. per acre, respectively.

In addition, therefore, to the experiments suggested in regard to wheat, with the view of determining—

1°. The absolute and relative efficacy of saltpetre and nitrate of soda on different varieties of the grain;

2°. The same on different varieties of soil;

3°. And under diversities of management,—as in the previous treatment of the land, &c.;

There may be added, in regard to oats and barley, another series of trial to determine—

4°. The relative effects of different proportions of the nitrate of soda, which is at present *supposed* to be specially beneficial to these kinds of grain. If any one be desirous of uniting this latter series with the former, it may be done thus—

Sulphate of Soda.	Nitrate of Soda, 1cwt. per acre.	Saltpetre.
Nitrate of Soda, 1½ cwt.		Nitrate of Soda, 1¼ cwt.

The vacant half-acre being as before left for the purpose of comparison. Such an entire series might be made at the same time on a field of Tartary and of potatoe oats, and on two or more varieties of barley.

These top-dressings may all be sown broad-cast—on the wheat most conveniently when the seeds are sown in April or May, and on the barley and oats when the fields have become distinctly green.

I may be permitted to add, as inducements to practical men, to try one or more of these experiments in the accurate manner above described:

1°. That the result will be directly available and of immediate practical value on his own farm, to the person by whom they are carefully made. That they will be permanently useful to his landlord (if carefully recorded), ought to be an inducement to the latter to give every facility and encouragement to his tenant in making them.

2°. That, instead of involving expense and outlay, which in many instances may ill be spared, *they are sure in almost every case to do more than repay the cost of making them*, by the increased quantity or value of the produce obtained. Any of the series of experiments, on the scale suggested, may be made for five pounds, so that were the outlay all to be lost, the accurate knowledge obtained in reference to the general tillage of his land, would be worth more money to the holder of a farm of a hundred acres.

3°. I need scarcely add, as a further inducement, the additional interest which such experiments give to the practice of farming—and the means they afford of calling forth the intelligence of the agricultural population. The moment a man begins to make experiments under the guidance of an understood principle, from that moment he begins to think. To obtain materials for thought he will have recourse to books—and thus every new experiment he makes, will further stimulate and awaken his intellect and lead him to the acquisition of further knowledge. Does it require anything more than this general awakening of the minds of the agricultural class, to advance the science of agriculture as surely and as rapidly as any of the other sciences, the practical application of which have led to those extraordinary developements of natural resources, which are the characteristic and the pride of our time?

III.—*Of Turnips.*

The raising of turnips is of such vast importance in the prevailing system of husbandry, that any improvement in the mode of culture must be of extensive and immediate benefit. Experiments so numerous and so varied have been made with this view, that it may almost seem superfluous in me now to make any further suggestions on the subject. But when experiments have been made with a view to one subject only, it often happens in all departments of natural science, that as new views are advanced or more precise methods pointed out, it becomes necessary to repeat all our former experiments,—either for the purpose of testing the results they gave us, or of observing new phenomena to which our attention had not previously been directed.

I. Numerous experiments, for example, have been made upon the use of bones in the raising of turnips, but they have been chiefly directed to economical ends, and so far with the most satisfactory results. But among fifty intelligent and thinking practical men, and who all agree in regard to the profit to be derived from the use of bones with the turnip crop, how many will agree in regard to the mode in which they act—how few will be able to give a satisfactory reason for the opinion they entertain! The same is true of theoretical chemists, some attributing their effect more especially to the earthy matter, others to the gelatine they contain. Dry bones contain about two-thirds of their weight of earthy matter, the other third consisting chiefly of animal matter resembling glue. Of the earthy matter five-sixths consist of phosphate of lime and magnesia, and the rest chiefly of carbonate of lime. Thus a ton of bone dust will contain—

Animal matter	746 lbs.
Phosphate of lime, &c.	1245 lbs.
Carbonate of lime, &c.	249 lbs.
	2240 lbs.

On which of these constituents does the efficacy of bones chiefly depend? Does it depend upon the animal matter? This opinion is in accordance with the following facts:—

1°. That in the Doncaster report it is said to be most effectual on calcareous soils,—for in the presence of lime all organic matter more rapidly decomposes.

2°. That horn shavings are a more powerful manure than bones,—since horn contains only one or two per cent. of earthy matter.*

3°. That before the introduction of crushed bones, the ashes of burned bones had been long employed to a small extent in agriculture, but have since fallen almost entirely into disuse.

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* This, I believe, is rather a matter of opinion than the result of a sufficient number of actual trials. Some trials made by Mr. Hawden (British Husbandry, I. p. 395) gave results very unfavourable to horn shavings.

4°. That old sheep skins cut up and laid in the drills, have been found to yield as good a crop of turnips and after-crop of corn, as the remainder of the field which was manured with bones.

5°. That "40 lbs. of bone dust are sufficient to supply three crops of wheat, clover, potatoes, turnips, &c., with phosphates,"* while one to two-thirds of a ton of bones, containing from 400 to 800 lbs. of phosphates, is the quantity usually applied to the land.

On the other hand, the quantity of animal matter present in a ton of bones (746 lbs.) is so small, and its decomposition so rapid during the growth of the turnips—while at the same time the effects of the bones are so lasting and so beneficial to the after-crop of corn—that many persons hesitate in considering the great excess of phosphates applied to the land, as really without any share of influence in the production of the crops.

Thus *Sprengel*, an authority of the very highest character, both in theoretical and practical agriculture, is persuaded that the phosphates are the sole fertilizing ingredients in bones, and he explains the want of success from the use of crushed bones in Mechlenburg and North Germany, on the supposition that the soils in those countries already contains a sufficient supply of phosphates, while in England generally they are deficient in these compounds.

Further, if the animal matter be the fertilizing agent in bones, why are not they of equal efficacy on grass land as upon turnips?

With the view, therefore, of leading to some rational explanation of the relative effects of the several constituents of bones, it would be desirable to institute comparative experiments of the following kind—

1°. With half a ton of bones per acre.

2°. With three or four cwt. of horn shavings or *glue* per acre.

3°. With two cwt. of burned bones per acre.

4°. With six or seven cwt. of burned bones per acre.

The quantity of burned bones in No. 4 is that which is yielded by a ton of fresh bones; that in No. 3 is upwards of five times what should be taken up by the crops—as great part of what is added must be supposed to remain in the soil, while *some must be dissolved and carried off by the rains.*

The result of such experiments as these, if made accurately on different soils, will lead us sooner to the truth than whole volumes of theoretical discussion.

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* *Liebig*, p. 84. The acre here spoken of is the Hessian, about three-fifths of the English acre. The English, therefore, will require 66 lbs.

II. Nitrate of soda has also been applied with great benefit in the culture of turnips. Some experiments, exceedingly favourable in an economical point of view, have been made by Mr. Barclay, of Eastwick Park, Surrey,* who found that one cwt. per acre, drilled in with the seed, gave as great a return of Swedes as 15 bushels of bones with 15 of wood ashes per acre, and when the nitrate of soda was sown broadcast, from 20 to 25 per cent. more. In every part of the country, therefore, this substance ought to be tried. And as this nitrate is very soluble in water, and may therefore be readily carried off by the rain, and as that only which is within reach of the plant is of any avail, I would suggest that not more than one-fourth of the whole should be drilled in with the seed, for the purpose of *bringing away* the plant; and that after the thinning by the hoe, the rest should be strewed along the rows by the hand or by the drill. In this way the whole energy of the salt being expended where it is required, the greatest possible effect will be produced.

III. I have already stated the reasons which lead me to anticipate highly beneficial effects to vegetation from the use of sulphate of soda; I would suggest, therefore, a trial of this salt on the turnips also, at the same rate of one cwt. per acre, and applied in the way above recommended for the nitrate of soda. Of course the intelligent farmer will vary the proportions and mode of application of these substances, as his leisure or convenience permit, or as his better judgment may suggest to him.

The entire series of experiments on turnips, above suggested, may be represented as follows, adding two plots for different proportions of the nitrate and sulphate of soda:—

Burned Bones, 2 cwt. per acre.	Nitrate of Soda, 1½ cwt. per acre.	Bone Dust, or Crushed Bones, 1 ton per acre.
Burned Bones, 6 or 7 cwt. per acre.	Sulphate of Soda, 1 cwt. per acre.	Horn Shavings, or Glue, 7 or 8 cwt. per acre.
Unmanured.	Sulphate of Soda, 1½ cwt. per acre.	Nitrate of Soda, 1 cwt. per acre.

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* Journal of the English Agricultural Society, I. p. 428.

Some of these experiments most of you may easily try. Those with the burned bones and horn shavings, which in this part of the country are less easy to be obtained, it is not to be expected that many of you will think of undertaking. I hope, however, that they will not be lost sight of by those who possess facilities for obtaining them in sufficient quantity to make a satisfactory experiment.

In many parts of the United States, gypsum is the universal fertilizer for every crop, and among the rest it is said to benefit turnips. The same opinion is entertained in Germany. I am not aware how far, in what way, or with what results, it has been applied to the turnip crop in this country. A simple mode of testing its efficacy, however, would be to strew it over the plants when in the rough leaf, on part of a field, the whole of which had been already manured in the ordinary way with fold-yard manure. The difference of produce would thus show its efficacy, in the given circumstances; and the experiment could be made effectually at the cost of a single cwt. of gypsum.

I have not included *rape dust* among the trials above suggested, though it is undoubtedly, under certain modes of management, a beneficial manure both to corn and turnip crops. There is also a diversity of opinion as to the cause of its fertilizing action, as well as a manifest difference in the effect of different samples of the dust on the same soil. Though, therefore, certain experiments which I may on a future occasion suggest, would undoubtedly throw light on the cause of the good qualities of this manure, yet as its action (taking different samples) is not *constant* on the same soil, results obtained with it cannot possess the same importance, either theoretical or practical, as those which are observed to follow from the use of bones and of saline substances, the composition of which is nearly invariable.

Many farmers, however, are in the habit of constantly using rape dust. If any of these could conveniently make experiments on the effect of different samples of the cake, from different kinds of seed, and from different oil mills, and would accurately note the results, they would perform an important service in preparing the way for that clear explanation of the cause of its fertilizing action, which is at present wanted,* and which experiment alone can discover to us.

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* Its good effects are generally attributed to the oil which is left in the seed, and its varying action to the different quantities of oil left in it by different crushers—I doubt, however, if the oil ought to be considered as more than a secondary cause of its beneficial action.

IV.—*Of Potatoes.*

1°. Nitrate of soda has been applied with great benefit to potatoes also. After the potatoes have been harrowed down and (hand) hoed, and the plants are four to six inches above the ground, it is applied by the hand round the stem of the plants, and the earth then set up by the plough. Mr. Turnbull, in Dumbartonshire, last year used it in this way at the rate of 1½ to 2 cwt. per Scotch acre, (1¼ English acres,) and the produce exceeded that of the land to which no nitrate was applied, by 20 Scotch bolls to the Scotch acre.

2°. Applied in the same way there is every reason to believe that the sulphate of soda would have a highly beneficial effect also. I repeat my recommendation that this substance should be fairly tried with every crop, because it is a product of our own manufactories, which can be supplied in unlimited quantity, and without the chance of any material increase of cost; while the nitrate of soda is already in the hands of speculators, and within a short period has risen in the market to the extent of nearly one-third of its former price.

In *plastering* their potatoes, the Americans generally put in a spoonful of gypsum with every cutting—a similar method, if preferred, might be adopted with the nitrate and sulphate of soda, though the chance of loss by percolation through the soil, would, by this method, be in some degree increased. In Flanders, wood ashes and rape dust are frequently thrown in by the hand, when each cutting is introduced.

3°. I shall have occasion hereafter to recommend to the attention of the practical farmer, many waste materials of various kinds, thrown out from our manufactories, the application of which to useful purposes would be a great national benefit. In reference to the culture of potatoes, I will here bring under your notice the chloride of calcium, which is said to have been beneficially applied to various crops, but to potatoes especially, with surprising effect. Under the influence of this substance the sunflower and maize have grown to the height of 14 to 18 feet, and potatoes have attained the weight of 2 to 3 pounds.* In Germany, Sprengel also found it useful to potatoes.—(*Chemie für Landwirthe, I. p.* 635.)

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* The *Rohan*, a French variety of potatoe lately introduced into the United States—by the ordinary mode of culture—yields tubers, very many of which weigh 3 lbs. and many attain to the weight of 5 lbs. When perfectly ripe, it is said to be an excellent table potatoe, and to be best in the spring.—***Albany Cultivator**, for **March***, 1841.

Thousands of tons of chloride of calcium may every year be prepared from the waste materials which flow into the river Tyne, from the alkali works upon its banks. Thousands of gallons of the solution of this substance yearly run off from the works of Messrs. Allan and Co. at Heworth, and might be procured for little more than the expense of collecting. It is also contained largely, though mixed with other substances, in the mother liquor of the salt pans; and from the numerous salt works on the coast might readily be obtained for trial. When prepared in the dry state, this substance rapidly *deliquesces* and runs into a liquid. The most convenient way of applying it, therefore, would be in the state of solution—so largely diluted as to have only a slight taste—and by means of a watering cart so contrived as to allow it to flow on the tops of the ridges and young plants, by which unnecessary waste would be prevented.

Without knowing the strength of the solution likely to be obtained from the works, it is impossible to give any idea of the quantity of the chloride of calcium which ought to be employed; but 500 gallons per acre may safely be used, if the solution be so far diluted as to have only a decided taste of the substance.

The experiments here suggested, therefore, require four patches, as follows:—

Nitrate of Soda, 1 to 1½ cwt. per acre.	Sulphate of Soda, 1 to 1½ cwt. per acre.
Chloride of Calcium, 500 gallons per acre.	Manure only.

These experiments are supposed to be made in ground already prepared for the potatoe crop, by the usual quantity of manure. I think it not unlikely, however, that by planting the potatoe in the midst of nitrate or sulphate (sprinkled over with dry soil) at the rate of half a cwt. per acre, and afterwards applying one cwt. per acre, when the plants are hoed, a crop might be obtained without the use of manure. Of course, such an experiment as this, though important to be made, should be tried cautiously, and on such a scale as to secure the experimenter from any serious loss.

In the above suggestions I have introduced nothing in regard to *mixed* manures—though where plants require for the supply of *all* their wants nine or ten different ingredients, of which the soil they grow in can perhaps yield in sufficient quantity only three or four, it is obvious that the very best consequences may follow from the employment of mixed manures. To this class belong common night-soil, urine, animalised carbon, *poudrette* (night-soil mixed with lime and gypsum), the *poudre vegetatif* (a mixture of soot and saltpetre), the *urate* (now manufactured in London), and many others.

The mode of preparing, and the special uses of these and other mixed manures, will be explained in the third part of these lectures, which will be devoted to the consideration of the nature and uses, and to the theory of the action of natural and artificial fertilizers. In the mean time it is desirable, in the first place, to obtain results from which the special action of each, when used *alone*, can be fairly deduced.

That these experiments may have their full value, it is indispensable that a measured portion of each field should be left without manure or dressing of any kind, in order that a true idea may be formed of the exact effect of each substance employed. Experiments are valuable to the practical man if they merely show the superiority of one species of manure over another, but they are insufficient to show how much each of them tends to increase the produce—or to enable us to arrive at a satisfactory explanation of the mode in which they severally act in promoting vegetation.

Among other important experiments lately published, to which the above observation is applicable, may be mentioned those of Mr. T. Waite, of Doncaster. The effects of nitrate of soda on his land were very striking, showing a remarkable increase of produce over bone dust, rape dust, or rotten fold-yard manure—but he does not seem to have determined the produce of the same land during the same season and *without manure*. We have, therefore, no term of comparison, by means of which we can ascertain the absolute or even the exact comparative effect of the different substances employed.

It has been well observed by Sir Humphry Davy, "that nothing is more wanting in agriculture than experiments in which *all the circumstances* are minutely and scientifically detailed, and that this art will advance in proportion as it becomes exact in its methods."* The above suggestions are submitted to practical men in the hope that they may assist in introducing such exact methods into our agricultural operations, and at the same time promote the theoretical advancement of the most important art of life.

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* Agricultural Chemistry, Lecture I.

Exact methods lead to theoretical discoveries, while these are no less certainly followed by important practical improvements.

No. II.

(*See Lecture II., p.* 44.)

In illustration of the effect of sudden alternations of temperature on vegetable substances, explained in a note subjoined to page 44, I quote with pleasure the following instructive letter from an ably conducted Monthly Journal published at Albany, in the State of New York, under the title of the *Cultivator*. It is extracted from the Number for March last :—

"In regard to Irish potatoes, a still thinner covering of earth than the one just mentioned suffices with us to preserve them from rotting. Indeed, it would seem as if they could freeze and thaw several times, during winter, without being destroyed, provided they are covered with earth all the time; for we often find them near the surface and perfectly sound, in the spring, when spading up the ground in which the crop had grown during the previous season. There they must have undergone freezing and thawing whenever the earth was in either state, as it often is to a much greater depth than the potatoe roots ever extend. Why should those roots always be destroyed when they freeze *above ground*, and not suffer equally when frozen *under ground?*

"The reason why potatoes, apples, &c., become soft, and rot when frozen and then thawed suddenly, uncovered and in open air, is the sudden thawing. You may put a heap of apples on the floor of a room, or other dry place, where they will freeze perfectly hard, and if covered close with any thing that will exclude the air, when the weather becomes warm enough to thaw, the apples will remain sound and uninjured, after they are thus closely thawed. The cover may be of the coarse tow of flax, or any article that will cover them close and exclude the air. So apples may be packed in a tight barrel, if full and headed up so as to exclude the air. They may be suffered to remain so in a garret, or any dry place where it freezes hard, and they will be found sound and free from injury, if the barrel remains tight till they are *thoroughly thawed*. It is the sudden thawing that causes the apples or other vegetables to become soft and rot.

"So if the fingers on your hand be frozen, and you expose them to sudden heat by warming them at the fire, and they suddenly thaw, the flesh will mortify and slough off. But, if you freeze your fingers or other limbs, and put them in snow, and rub gently till they thaw,—or if put into a pail of water just drawn from the well, which will be less cold than your frozen fingers,—they will thaw slowly, and suffer but little injury.

"So during the early autumnal frosts in September, if the morning after the frost is cloudy, the frost will be slowly drawn from the frozen vegetables, and they will be uninjured; but if they receive the rays of the early and clear sun, they thaw so suddenly, that they will hang their heads and perish. If wet with water from the well, long enough to extract the frost before the sun shines on them, they do not suffer.

"Onions are a difficult root to keep in winter. If they are put in a cellar warm enough to save them from frost, they will vegetate and be deteriorated. I put them in the warehouse, where they freeze as hard as if out of doors. If in a heap, I cover them close with some old clothes, or any thing that covers close, to exclude the air. The same if in boxes or casks. They freeze hard, but it does not appear to injure them for present use, if thawed by putting them into a pail of fresh-drawn water, to draw out the frost just before cooking them. Onions thus kept, will be in good condition in the spring, after thawing under cover from the air.

"I put parsneps, carrots, beets, &c., in boxes or casks, and then cover them with potatoes, which preserves them from drying."

In further illustration of this subject I need only recal to the recollection of the gardener the well known fact, that, when the winter frosts begin to set in, and his finest flowers to be nipped, those continue to blow the longest, on which the sun's rays fall latest in the day. Dahlias protected in this way will bloom occasionally for weeks, after those which regard the eastern sky are completely withered.

Professor Lindley has published a series of valuable observations on the effects of extreme cold upon plants. The general results of these observations are stated in his "*Theory of Horticulture*," p. 88. But the conclusions at which he has arrived are deduced from the appearance presented by the plant after it was *thawed*. He found the tissue more or less lacerated, the contents of the air and sap vessels intermingled, and the colouring matter and other secretions decomposed. He attributes the laceration to the freezing and consequent expansion of the juices, but this cannot be the necessary consequence of that freezing, since it does not appear, if the whole tuber or leaf be slowly thawed. I would explain the phenomena as follows:—

1°. When the leaf, fruit, or tuber freezes, the fluid portions slightly expand in becoming solid, but the air in the air vessels contracts in at least an equal degree, and thus allows a lateral expansion of the sap vessels sufficient to prevent lesion. When the temperature is slightly raised, the air expands but slightly, and ice is melted long before the gaseous substances reach their original bulk.

2°. But if the rays of the sun strike suddenly upon the leaf or fruit, the surface may at once be raised in temperature 30° or 40° F. The air will consequently expand suddenly, and before the sap is thawed may have distended and torn the vessels, and caused sap and air to be mutually intermingled.

3°. But the moment the sun's rays strike upon the green leaf, its chemical functions commence. It begins to absorb and decompose carbonic acid: and as in the frozen part of the leaf the circulation is not, and in consequence of the lesion cannot be, established, the chemical action of the sun's rays must be expended upon the stagnant sap; and hence those changes not only in the sap itself, but even in the solid parts, which are seen to take place in the withered leaf.

4°. Though not in a state of growth, the tuber of the potatoe contains the living principle, and there must be such a circulation going on in its interior as to maintain an approximate equilibrium of temperature throughout its substance. A sudden thawing of the exterior, will, as in the leaf, expand the air before the circulation can be established throughout the frozen mass. The solid, fluid and aeriform substances which nature has separated and set apart from each other, will thus all be intermingled, and from their mutual action, those chemical changes of which we know the starch of the potatoe to be susceptible, will speedily ensue;—in other words, the potatoe will rot.

The practical applications of these views are numerous. If a sudden frost come on,—protect your delicate flowers in the early morning from the rays of the approaching sun, and cover with straw or earth the potatoes which have been left overnight in the field.

No. III.

RESULTS OF EXPERIMENTS ON PRACTICAL AGRICULTURE DURING THE SPRING AND SUMMER OF 1841.

See Appendix, No. I., and Lectures VIII. and IX.

In a previous article inserted in this Appendix, and which was published early in the present spring (April, 1841,) I ventured to offer to the practical agriculturist some suggestions in regard to the *experimental use* of certain unmixed manures. From the results of these experiments, which I was quite sure some of the many zealous agriculturists of the day would be induced to undertake after the manner, and with the precautions, I had pointed out, I anticipated a two-fold advantage. In the first place, that important practical benefits to the agriculture of certain districts would be derived from them, and secondly, that interesting and important light would be thrown by them on many parts of agricultural theory. It is by experiment that all the remarkable results—theoretical as well as practical—of modern chemistry have been arrived at; but by experiments cautiously made, frequently repeated, and logically reasoned from. The proceedings of the practical farmer are a continued course of experimental trials, and to convert him into an experimental philosopher, and to lead him to philosophical results, it is necessary only that his experiments should be made *with a constant reference to weight and measure*, and should be repeated under varied and carefully noted conditions—and that he should be taught to draw from them no conclusions more general than they really justify.

The following results of experiments made during the past summer confirm all my anticipations. Though necessarily somewhat limited, and local in their nature, they, nevertheless, present on the whole a beautiful illustration of what we have yet to expect from a continuation of such experimental researches, conducted in so skilful a manner. I need not especially commend the experiments of Mr. Fleming; for I can scarcely, I think, render a better service to practical agriculture than by placing all of them in the hands of practical men, and earnestly commending them to their careful consideration and imitation.

I. Experiments made near Aske Hall, on the property of the Earl of Zetland.

HALF AN ACRE.

Soot—put on 24th May—10 bushels cost 6s. 6d.

Weight of grass when mown, 3 tons 16 cwt.
Weight when made into hay, 1 " 15 "

HALF AN ACRE.

Salt—put on 24th May—3 bushels cost 6s. 6d

Weight of grass when mown, 3 tons 19 cwt.
Weight when made into hay, 1 " 16 "

HALF AN ACRE.

No Manure.

Weight of grass when mown, 3 tons 12 cwt.
Weight when made into hay, 1 " 6 "

HALF AN ACRE.

Nitrate of Soda—put on 24th May.
4 stones cost 11s.

Weight of grass when mown, 4 tons 10 cwt.
Weight when made into hay, 1 " 12 "

HALF AN ACRE.

Sulphate of Soda (in crystals)—put on 24th May—4 stones cost 10s.

Weight of grass when mown, 3 tons 3 cwt.
Weight when made into hay, 1 " 9 "

HALF AN ACRE.

Sulphuric Acid—⅓ put on 26th May, ⅓ put on 7th June, ⅓ put on 11th June—15lbs. cost 5s.

Weight of grass when mown, 3 tons 4 cwt.
Weight when made into hay, 1 " 6 "

General Results per imperial acre.

	Quantity applied.	Cost.	Produce when cut.		Produce in hay.		Hay from 100 of grass.	Increase in hay.	
			tons	cwt.	tons	cwt.		tons	cwt.
Common Salt. .	6 bshls.	13s.	7	18	3	12	52	1	0
Soot . .	20 "	13s.	7	12	3	10	53	0	18
Nitrate of Soda .	112 lbs.	22s.	9	0	3	4	36	0	12
Sulphate of Soda.	112 "	20s.	6	6	2	18	46	0	6
Sulphuric Acid . .	30 "	5s.	6	8	2	12	40	0	0
No Manure. .	—	—	7	4	2	12	36	—	—

N.B. The cost of the manure does not include the expense of laying it on.

Mr. Turner, his lordship's agent, thus writes :—

"The plan I followed in putting on the different manures, and the quantities used, accorded as nearly as I could manage it, with the directions given in your published lectures.

"The field on which the experiments were tried is situate in a high, bleak climate, and consists of a thin light soil, upon a bad subsoil of barren clay resting upon limestone. It had been completely exhausted by a succession of white crops, and was full of weeds and quickens. I had it well ploughed, and took a crop of drilled turnips fairly, but not extravagantly, manured. The crop was a poor one. I ploughed the land as soon as the turnips could be got off. Drained it; and in the spring worked it very fine. The following August I sowed it away with grass seeds without a crop. The seeds came up beautifully, and were the admiration of all who saw them, keeping a deep green through the winter, and beginning to grow early in the spring; and it was on this crop that the experiment was tried early in the succeeding summer.

"I need scarcely remark, that the crop of grass for such land was enormous, and has fully repaid the money expended upon it, with the exception of draining, and in two or three years I have no doubt but it will repay this also."

Remarks.—On comparing the effect of these several top-dressings as indicated by the results above stated, the reader will be struck with the extraordinary increase caused by the addition of common salt. I have in the text (Lecture IX., p. 279) indicated a principle which may serve to explain *in some measure* both the localities in which the use of common salt may be expected to be beneficial, and the reason why in many parts of our island the employment of this substance has not been attended by any large measure of success. The position of the land experimented upon by Mr. Turner, is such as to lead us to expect it to be improved by common salt, according to the views there stated.

The nitrate of soda produced less effect than either the common salt or the soot, but it gave an increase which was double of that yielded by the sulphate of soda. The latter salt, however, was applied in the state of crystals, which contain 55 per cent. of water, so that less than one-half of that weight of *dry* salt was used, which was recommended in the suggestions I offered for the employment of this substance in practical agriculture. At the same time, the price paid by Mr. Turner for this salt was *four times* as great as it ought to have been. Any quantity of the *dry* sulphate of soda may be procured at 10s. a cwt.*

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* By addressing a note to Messrs. Allan & Co., Heworth Alkali Works, Newcastle, who forward it in casks to all parts of the country.

The most valuable practical suggestion to be derived from these experiments is certainly this—that a liberal use of common salt is likely to increase in a great degree the produce of grass in the locality where they were made, and on the same kind of soil. This valuable discovery will far more than repay the expense and trouble of the entire series of experiments. No application can be so cheap as this, *so long as it succeeds.* At the same time a mixture of the other substances—the nitrate and the sulphate, which were partially successful—might possibly prove still more efficacious on the grass, and might be expected even to ameliorate the condition of the land for the further production of white crops. In a future part of this Appendix I intend to offer some suggestions in regard to the *kind* and *quantity* of the ingredients which may, with probable advantage, enter into the constitution of these *mixed manures.*

I have calculated and introduced into Mr. Turner's table an additional column, exhibiting the weight of hay yielded by 100 lbs. of grass, with the view of showing the relative succulence of the several crops when cut. As a general rule, the weight of dry hay does not exceed one-fourth of the weight of the grass when cut. In the experiments of Mr. Turner, however, the weight of hay in every case was much beyond this quantity—the most succulent crop, that to which no dressing was applied, yielding 36 per cent. of hay. This general result may have been partly due to the state of ripeness in which all the grasses were cut, while the greater produce of hay from the dressed portions may indicate the relative ripeness, and therefore dryness, of each when cut down.

It is evident, therefore, that the relative values of crops of grass or clover are not to be judged of by the several weights when green, but by the weights of the dry hay. This is further confirmed by the results of an experiment with nitrate of soda, communicated to me by Mr. Carruthers, of Warmonbie, near Annan, in which the relative weights of hay obtained were *much more in favour* of the use of the nitrate than the several weights of grass yielded by the dressed and undressed portions of the field. On the contrary, from a field on Oliver Farm, near Richmond, Mr. Sivers informs me, that the weight of hay was *much less in favour*[*] of the use of the nitrate of soda than the relative weights of grass. In all cases, therefore, the weight of the dry crops obtained by different methods should be compared with each other, as the safest test of the relative merits of the several modes of procedure by which they have respectively been raised.

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[*] In Mr. Sivers' experiments, 100 square yards, *nitrated*, gave 68 stones of hay, unnitrated 52 stones, but when dry they were reduced to 12 stones each. How very much more succulent these grasses were than those of Mr. Turner!

II. Experiments made at Erskine, on the property of Lord Blantyre.

I insert the clear and well-digested statement of his Lordship's agent without alteration:—

"*Freeland, Erskine, by Old Kilpatrick, Glasgow,*
29th July, 1841.

Sir—Agreeably to Lord Blantyre's instructions I send you a copy of the results of some experiments with manures on young grass for hay, undertaken on two separate pieces of land—the one a very good light soil (subsoil gravel); the other stiff clay soil with a clay subsoil. The manures were applied on 1st May, the hay cut on the 1st and weighed on the 19th July current; the extent of each plot one-twentieth of an imperial acre. From the small extent of each plot it will be evident that the results cannot be exactly depended on, farther than as a general result; because, in so small a portion of land the least variation in the soil or crop naturally will affect the results very materially; still, on the whole, I am of opinion that the experiment gives the comparative view of the value of the different manures used pretty nearly.

"One thing has astonished us with regard to soda (nitrate). On all the fields I have observed it sown on, the part dressed has a much greater vigour of aftermath than where no nitrate of soda was given: showing that this manure is not so evanescent as was generally supposed.

"I am, Sir, your most obedient servant,
"Jas. Wilson."

Experiments with Manures as a top-dressing for Hay, at Erskine, 1841.

The Dressings were applied 1st May, the Grass cut 1st July, and the Hay weighed 19th July.

No. of Plots.	APPLICATION.	I. Exp.—good light soil, subs. gravel.										II. Exp.—clay soil, subsoil clay.									
	Manures used, and quantities applied, to each plot of 1-20th of an acre.	Weight on 1-20th of an acre in pounds.	Increased weight on 1-20th of an acre.	Total produce per Imperial Acre				Total additional weight per Imperial Acre.				Weight on 1-20th of an acre in pounds.	Increased weight on 1-20th of an acre.	Total produce per Imperial Acre				Total additional weight per Imperial Acre.			
				ts.	*cwt.*	*qrs.*	*lbs.*	*ts.*	*cwt.*	*qrs.*	*lbs.*			*ts.*	*cwt.*	*qrs.*	*lbs.*	*ts.*	*cwt.*	*qrs.*	*lbs.*
1	1lb. sulphuric acid, diluted in 47 galls. water,	271	44	2	8	1	16	—	7	3	12	256	26	2	5	2	24	—	4	2	16
2	6lbs. saltpetre (nitrate of potash)	322	95	2	17	2	0	—	16	3	24	286	56	2	11	0	8	—	10	0	0
3	6lbs. nitrate of soda,	339	112	3	0	2	4	1	0	0	0	282	52	1	10	1	12	—	9	1	4
4	6lbs. sulphate of soda (in crystals)	292	65	2	12	0	16	—	11	2	12	232	2	2	1	1	20	—	0	1	12
5	17lbs. gypsum,	254	27	2	5	1	12	—	4	3	8	240	10	2	2	3	12	—	1	3	4
6	1 bush. wood charcoal (pounded)	277	50	2	9	1	24	—	8	3	20	257	27	2	5	3	16	—	4	3	8
7	¼ bush. common salt, 25 galls. water,	294	67	2	12	2	0	—	11	3	24	269	39	2	8	0	4	—	6	3	24
8	1 gallon ammoniacal liquor, 47 galls. water,	277	50	2	9	1	24	—	8	3	20	201	—	1	15	3	16	—	—	—	—
9	No application,	227	—	2	0	2	4	—	—	—	—	230	—	2	1	0	8	—	—	—	—

REMARKS.—It will be observed in these experiments, that the saltpetre and nitrate of soda produced *nearly* an equal increase on both kinds of soil, the nitrate of soda having the greater effect on the light, the nitrate of potash on the heavy soil. Next to these on the light soil are the common salt and sulphate of soda, though on the heavy soil the common salt had the better effect of the two. It is to be observed, however, that in this case the sulphate was used in crystals, and therefore only in half the quantity recommended. Had twice the quantity been employed upon the *light* soil the produce might have equalled that from the nitrates.

It is a singular illustration, however, of the necessity of applying different substances to different soils—that so far as this experiment is to be depended upon, the sulphate of soda almost entirely failed on the heavy land.

The most valuable practical deduction from these experiments also, is, that on both the soils in question, the grass land, *in its present condition*, may be salted to advantage. At the same time, it appears probable that on the light soil the increased produce would amply repay the cost of applying either nitrate or sulphate of soda at the rate of 120 lbs. per acre—the latter being in its dry or uncrystallized state.

The effect, generally, of all the dressings is strikingly greater on the light soil—a fact which speaks strongly in favour of the adoption of any of those methods by which the openness and friability of the land has been found to be permanently promoted. On the stiff soil, even the ammonia, by some deemed so vitally necessary to vegetation, appears to have produced no sensible alteration.

III. Experiments made under the immediate superintendence of W. Fleming, Esq., of Barochan, near Paisley, and on his own property. The statement is drawn up by Mr. Fleming himself.

1.—*Experiments on Hay with Nitrate and Sulphate of Soda and with Gypsum.*

On Covenlea the dressings were applied on the 22nd of April, and the hay cut on the 2nd of July; on the other fields the nitrate and gypsum were applied on the 12th of April, and the hay cut on the 9th of July.

No.	Field.	Description of Dressing.	Rate per imp. Rood.	Weight per Rood, green.	Weight when stack'd
1	Covenlea.	Nothing.	—	3361 lbs.	1120 lbs.
2	Do.	Nitrate of Soda.	40 lbs.	4907 "	1636 "
3	Do.	Sulphate of Soda.	40 lbs.	3966 "	1322 "
4	Do.	Gypsum.	10 lbs.	3831 "	1277 "
1	Crook's High.	Nothing.	—	4436 "	1478 "
2	Do.	Nitrate of Soda.	40 lbs.	4999 "	1666 "
1	Crook's Low.	Nothing.	—	2185 "	728 "
2	Do.	Nitrate of Soda.	40 lbs.	3764 "	1254 "
3	Do.	Gypsum.	80 lbs.	3110 "	1036 "

Character of the Soil.—Nos. 1, 2, 3, and 4 were good sharp soil, on *rotten* rock, (decayed trap,) all as near as possible the same description of land, drained, and lying together. Nos. 1 and 2, Crook's High, stiff clay, drained; the hay was after wheat. Nos. 1, 2, and 3, Crook's Low, light clay-loam, drained; the hay was after barley.

N. B. The above is the average of trials in three parts of the Covenlea field; a small portion of moss was also sown with nitrate of soda, in the low part of the same field, but no benefit was observable, beyond the usual dark green colour which appeared about ten days after the application. The sulphate of soda, although evidently beneficial, does not produce the dark green colour. In the Crook's fields the effect of nitrate of soda in producing the dark green colour was as remarkable as in the Covenlea field. The gypsum on both fields seems to have had a good effect, particularly on the aftermath clover.

Remarks.—In these experiments also the sulphate of soda was used in only half the quantity recommended. By referring to the prices paid by Mr. Fleming, it will appear that the use of sulphate of soda gave an increase of 200 lbs. of hay for 1s. 9d. (or 500 lbs. for 4s. 5d.), while the nitrate of soda gave an increase of 516 lbs. for 7s. 10d.; so that, though the actual increase of hay per rood was considerably less by the use of the sulphate, yet that increase was obtained at little more than half the cost of the same weight of increase derived from the nitrate. A similar remark applies to the gypsum, so that these experiments give ample encouragement for the application of both these substances in somewhat large quantity to succeeding crops, on the same land.

2.—*Experiments on Winter Rye, dressed with Nitrate of Soda, Lime with Potash, Sulphate of Soda, and Muriate of Ammonia (Sal Ammoniac.)*

The applications were made on the 14th of April, the grain was cut on the 9th of August, and thrashed on the 25th.

No.	Field.	Description of Dressing.	Rate per rood imperial	Weight of Grain per rood.	Weight of Straw per rood.	Bushls per rood.
1	Garden Plot.	Nothing.	—	160 lbs.	1024 lbs.	3⅛
2	Do.	Nitrate of Soda.	40 lbs.	336 "	1664 "	6⅛
3	Do.	Lime and Potash.	40 "	272 "	1344 "	5¼
4	Do.	Sulphate of Soda.	40 "	224 "	1152 "	4¼
5	Do.	Mur. of Ammonia.	5 "	232 "	1216 "	4¼

Character of the Soil.—Tilly clay, which had been trenched, and in potatoes the year before. The Rye was sown on their being lifted in October, 1840.

N. B. As early as the end of April the effects of the nitrate of soda were very apparent from the dark green colour produced, and broad leaves, and after it was ripe the heads were longer than any of the others; but it was so strong that it was laid a month before it was cut; none of the others were laid. Every application seems to have done good, by increasing the produce. The potash and lime was made by slaking quick-lime and sand with a solution of potash, and allowing them to lie together for a month. As much was used as contained 1 lb. of carbonate of potash to the pole.

REMARKS.—From these experiments, it appears that, besides the proportionate increase of straw, that of grain was

From nitrate of soda,	12 bushels	for 31s. 0d., or 2s. 9d. pr. bush.;	
" lime and potash,	7 "	for 33s. 6d., or 4s. 9d.	"
" sulphate of soda,	3 "	for 7s. 0d., or 2s. 4d.	"
" sal-ammoniac,	5 "	for 10s. 9d., or 2s. 2d.	"

Although, therefore, the total increase by the employment of sulphate of soda and muriate of ammonia, in the proportions actually put on, was not so great as by the use of the other two dressings, yet this increase was obtained at a considerably less cost per bushel. The lime and potash, though producing an important effect, will probably not yield a remunerating return with this crop *on this soil*, while the results hold out a fair inducement for the trial of the last two dressings in larger and varied proportions.

The five samples weighed respectively,—45⅗, 51¾, 51⅘, 52⅗, and 46⅘ lbs. per bushel, so that, while on all the dressed plots the grain was heavier than on the undressed, that which was dressed with sulphate of soda was considerably the heaviest.

3.—*Experiments on Wheat field, Crook's* (*crop*, 1841.)

The applications were all made on the 13th of April, and the crop was reaped on the 2nd of September.

No.	Description of Top-dressing.	Rate per Scotch acre.	Weight of produce of Grain of 1-8th acre	Weight of Grain pr bshl.	Weight of total produce, *when cut*, of 1-8th an acre.
1	Nitrate of Soda.	160 lbs.	209 lbs.	63 lbs.	9,500 lbs.
2	Potash and Lime.	160 lbs. 40 bush.	210 "	62 "	8,930 "
3	Common Salt.	160 lbs.	249 "	62 "	12,540 "
4	Mur. Ammonia	20 lbs.	208 "	62 "	8,360 "
5	Nitrate of Soda and Gypsum.	80 lbs. 160 bush.	214 "	62 "	8,620 "
6	Nitrate of Soda and Rape-dust.	80 lbs. 5 cwt.	240 "	62¼ "	11,970 "
7	Mur. Ammonia and Lime.	20 lbs. 40 bush.	230 "	63 "	9,500 "
8	Common Salt and Lime.	28 lbs. 80 bush.	200 "	63½ "	8,740 "
9	Nothing.	—	190 "	61 "	8,050 "

Character of the Soil.—The land was a heavy loam, and of as nearly as possible the same quality. It had been in potatoes, and the wheat was sown when they were lifted in October, 1840.

The produce of ⅛th of a Scotch acre, thrashed and weighed and well cleaned, gave an *average* of from 32 to 33 bushels of 61 lbs. each per Scotch acre of grain.

REMARKS.—This table presents us with two remarkable results,—that obtained by the use of common salt, and that from a mixture of soda and rape-dust. Thus, exclusive of the straw,—

Nitrate of soda alone	gave 152 lbs. of wheat for 31s., or 12s. 2d. per bushel;
Nitrate with rape-dust	gave 400 lbs. of wheat for 43s. 6d., or 6s. 9d. per bushel;

Common salt	gave 472 lbs. of wheat for 3s 6d., or 6d. per bushel.

The increased produce, by the use of common salt, is by far the most valuable result to Mr. Fleming in an economical point of view, and plainly indicates the kind of application he can most profitably make—to his wheat crops at least—on land similar to the above, and in the district where he resides.

Neither the nitrate of soda nor the mixture of this salt with rape-dust, gave such an increase as to repay their own cost, unless when corn is very high. It is interesting, however, to observe that the mixture with rape-dust gave so large an increase, though the value of this particular experiment is lessened by the absence of any trial with rape-dust alone, by which the effect of each of the ingredients ought to be judged of. I have reckoned the rape-dust at £7 a ton, so that 5 cwt. would cost 28s., and we know that a top-dressing of this substance alone, in a somewhat larger quantity, gives a remunerating return in many of our wheat lands.

Mr. Outhwaite, of Banesse, in the North Riding of Yorkshire, a skilful and enterprising practical farmer, who has for some years been using rape-dust over a great breadth of his wheat crops, has favoured me with the result of one of his more accurate trials on spring wheat, made during the past season. The wheat was sown after turnips taken off in April, and part of the field was dressed with rape-dust at the rate of 5¾ cwt. (or at £7 a ton, of 40s.) per acre. The produce of the dusted portion was 39 bushels, and of the undusted 29 bushels per acre, and the increase of straw was one-fifth of the whole. Both samples were of equal weight, and sold at the same price,—8s. 3d. per bushel. In this experiment the increased 10 bushels cost 40s., or 4s. per bushel, giving, on a large breadth of land, a handsome remuneration.

These results will, I trust, encourage others to make trials similar to those of Mr. Fleming and Mr. Outhwaite; while these gentlemen will, doubtless, be induced each to try that application which has succeeded so well in the other's hands. It might be useful as well as interesting to compare the produce of four plots arranged and dressed as follows:—

Common Salt.	Rape-dust.	Common Salt and Rape-dust.	Nothing.

4.—*Experiments on Early Potatoes*, 1841.

All were dunged in the usual manner with farm-yard manure, at the rate of about 30 cubic yards per acre. The potatoes were all planted on the 25th of March, on the same *heavy black soil*. The several dressings were applied on the 20th of May, and the potatoes were all lifted on the 28th of September.

No.	Description of Top-dressing.	Rate per imp. acre.	Produce per imp. acre.	Weight of Produce of 18 yards drill.	
1	Nothing.	—	66 bolls.	77 lbs.	*Note.*—The peck is 35 lbs. weight, and 16 make a boll or 5 cwt.
2	Nitrate of Soda.	160 lbs.	80 "	93 "	
3	Sulphate of Soda.	200 "	73 "	86 "	
4	Do. & Nitr. of Soda.	200 "	107 "	124 "	

This break of ground consists of a piece of poor clay mixed with moss, about 9 inches deep; subsoil a very stiff blue till. The dung was old from the farm-yard, about the ordinary quantity (30 cubic yards per acre) spread upon the land, and dug in. The potatoes were drilled in with the hoe; as the ground was wet the plants came up but weak. The nitrate of soda was sown before the other top-dressings, and had remarkably quick effect, as it showed the third night after being sown. The sulphate of soda does not occasion the dark green colour which is seen upon the potatoes after the dressing of the nitrate, but there is not the smallest doubt of its beneficial effects, although not in so great a degree as the nitrate. The mixture, which is composed of $\frac{2}{3}$ds of sulphate of soda and $\frac{1}{3}$rd of nitrate, has a wonderful effect in strengthening the growth (which it keeps longer than with nitrate alone), and the mixture has the same effect in producing the dark green colour as the nitrate alone.

Remarks.—That a *mixture* of substances is likely to be more efficacious as a dressing, than the application of one substance alone, except in peculiar circumstances, is consistent not only with long practical experience—for how many substances are mixed together in farm-yard manure?—but also with the theoretical principles laid down in the text.* These experiments upon potatoes show that this crop upon Mr. Fleming's land was benefitted by both nitrate and sulphate of soda, but in a vastly greater degree by a mixture of the two. And I might consider my suggestion in regard to the employment of sulphate of soda as a manure, to have been of no mean use in practical agriculture, had it led to nothing else than to this happy mixture of Mr. Fleming.

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* See Lectures IX. and X.

I have received also from Mr. Fleming's gardener (Mr. Alexander Gardiner) a very well digested and well drawn up paper, detailing numerous experiments made by himself during the past summer. Among these is one upon the use of this same mixture upon the potatoe crop, which I shall quote in his own words:—

"April 26th.—Planted potatoes of the red Don variety, soil a mellow loam, two feet deep, subsoil yellow till. Farm-yard dung was trenched in some days before planting, at the rate of 40 cubic yards per acre; sets drilled in with the hoe. Plants came up very regular, and were top-dressed with a mixture of ½ sulphate and ½ nitrate of soda on June 2nd, at the rate of 2 cwt. per acre. They grew very strong after this application. *Stems six and seven feet in length*, dark green, and the produce, when lifted in October, was 16 Renfrewshire pecks of 35 lbs. each per Scotch fall of potatoes fit for market."

This produce is equal, I believe, to about 26 tons per Scotch, or 21 tons per imperial acre, about equal to that of Mr. Fleming with the same mixture. And what an amazing luxuriance of vegetation, to yield at once stems 7 feet in length and upwards of 20 tons of tubers per acre!

Those who are the most sceptical in regard to the benefits to be derived from agricultural experiments, when well conducted, will scarcely question the importance of this result—the most backward in making experiments will be anxious to repeat this upon his *own* potatoes. The cost of the mixture to be applied in the quantity used by Mr. Fleming is as follows:—

		s.	d.
Sulphate of Soda	75 lbs. *dry* at 10s. per cwt. or 150 lbs. in crystals at 5s. . . .	6	9
Nitrate of Soda . .	75 lbs. at 22s.	14	9
		21	6

The return for this 21s. 6d. was in each of the above cases upwards of 8 tons of potatoes.

I may here mention also two other interesting experiments of Mr. Gardiner, in which he tried the effect of sal-ammoniac upon his potatoe crop,—

1°. In the one he mixed sal-ammoniac, previously dissolved in water, in the proportion of 1 lb. to each cubic yard of a compost formed from the refuse of the garden, and planted early potatoes with it at the rate of 35 cubic yards per acre. The produce was one sixth more than when no ammonia was used. The variety of potatoe was Taylor's forty-fold, the soil moss and clay. The cost of this application was 19s. per acre.

2°. Sal-ammoniac, dissolved in water, was sprinkled on moss or peat earth, at the rate of 20 lbs. to a ton of earth, and, after strewing a little lime at the bottom of the drills, this mixture was put in at the rate of 2 tons per acre. The potatoes were 14 days later in coming through the ground than the same variety planted with farm-yard manure. They were strong in the stem, of a dark green colour, and equal, in point of produce, to the others. The variety of potatoe was the Irish apple, the soil a very light brown loam, of that description locally named deaf.

I may observe on this latter experiment, that the application is not so simple as it appears. The lime would decompose the sal-ammoniac, and form *chloride of calcium*, while ammonia would be liberated. The effect, therefore, may be partially due to both. It will be recollected that in a previous part of this Appendix I suggested the trial of this chloride of calcium as a top-dressing for various crops.

6.—*Experiments on Moss-Oats, sown about* 1*st May*, 1841, *top-dressed* 25*th June.*

No.	Top-dressing per pole (imperial).
1	Nothing.
2	Bones dissolved in sulphuric acid and nitrate of soda ¾ lb.
3	Sulphate of soda ½ lb., bone dust ½ peck.
4	Potash 1 lb., lime and bone dust ½ peck.
5	Chloride of calcium 1 lb., bones ½ peck.
6	Lime, potash, and chloride of calcium, ½ lb. each.
7	Potash and lime, nitrate, and bones, ¼ lb. each.

Character of the Soil.—Moss 4 feet to clay. No. 2 the best crop and heaviest grain (not thrashed). Nos. 3, 4, and 5 not so good as No. 2, but all much better than Nos. 1 or 6. No. 6 the worst—not better than No. 1. No. 7 very good—next to No. 2.

"These top-dressings were applied on the 5th of June, and by the 24th there was a striking improvement, especially on No. 2 and No 7. It was quite visible in greater strength and evenness of crop. One or two of the others also showed improvement, but not so visibly as to merit particular notice. I examined them from time to time, and at different dates: the appearances much the same as noticed upon June 24th. I again examined them a few days before they were cut, when I was much satisfied with No. 2; the straw appeared to me as stiff and shining, and the ear as well filled, as if it had been grown upon stiff loam, and I *consider the same dressing, applied to grain crops upon moss, will insure a good crop of well-filled oats.* No. 7 was nearly as good, but the want of the bones being dissolved was a drawback. However, I consider the two merit the expense of another trial."

REMARKS.—These experiments of Mr. Fleming on moss oats may be considered as affording another illustration of the benefits which are yet to accrue to practical agriculture from the suggestions of natural science. It is well known to those who have directed their attention to the reclaiming of peat lands, that the crops of oats raised on such land yield abundance of straw, but that the ear is small and badly filled. It is also well known that *claying* such lands is an almost unfailing remedy for this defect in the ear, as well as for the less important one which is also observed in the straw. My friend, Mr. Alexander, of South Bar, a neighbour of Mr. Fleming, and, like him, extensively engaged in the improvement of peat lands, finding, as most other persons have, that in some localities the claying of his land was very expensive,[*] conceived the idea that some chemical application might be made to this soil, which would supply what the defective oat plants required, and thus supersede the necessity of *claying*. He was pleased to communicate this opinion to me—stating the defect in the crop, and asking a chemical remedy. Looking chiefly to what was evidently required by the ear, I suggested a trial of various mixtures, in all of which,—from an idea that phosphates, among other substances, might be necessary to *complete* the ear—bone-dust formed a necessary part. The result of these suggestions is seen in the above experiments of Mr. Fleming. They have been varied and improved upon, as Mr. Fleming's united chemical knowledge and practical skill enabled him to do, and as *first* results on a new field of research,

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[*] Mr. Garden, of Glenae House, near Dumfries, a gentleman to whom, though personally unknown, I am indebted for many valuable communications, informs me that, in improving his porous peat lands, he has found it necessary to lay on a coating of clay six inches thick, at an expense of £15 an acre. A coating of two or three inches on *their* peat, he says, sinks down, and in a few years descends beyond the reach of the plough, and hence it is more economical to lay on at once an entire soil of six inches.

Nos. 2 and 7 may be considered as highly encouraging, if not, indeed, eminently successful. Too much confidence, however, must not be placed on the effects observed in one or two instances; yet I hope those above stated are such as will induce others to repeat the experiments with equal care, in order that another year, affording us more numerous results, may enable us to base our conclusions upon a larger experience.

6.—*Experiments upon Oats top-dressed with Sulphate and Nitrate of Soda (lower end of Barn Park.)*

"The first was sown on the 11th May, viz., 3 ridges with sulphate of soda, at the rate of 1½ cwt. per acre. This was examined from time to time, but there appeared to be little, if any, difference from the general crop (it has not yet been thrashed.) Next, 3 ridges were sown with nitrate of soda, at the rate of 80 lbs. per acre. This made a little alteration both in colour and strength, but it was too little to make a very decided difference. Also, alongside of the last-mentioned, a piece was dressed with a mixture of sulphate and nitrate of soda, in the proportion of ⅔rds of the former to ⅓rd of the latter. This immediately took the lead of the others both in colour and strength, so much so, that by May 27th it could be seen from a distance. Many examinations were made of them all during the season, and this always appeared the best. A few days before it was cut, it showed the largest and best filled ear. There was a piece of yellow-coloured earth at the bottom of the field, showing the presence of iron, upon which was sown potash and lime. The plant was yellow and sickly-looking, but immediately after the application it acquired a dark green colour, and became vigorous, and yielded a crop at least equal to any in the field. There were some other dressings put on other ridges of this field, but it was dry weather directly after they were sown, and the crop was too far forward before they began to take effect to say any thing decided about them. By mistake there were two varieties of oats sown upon the field, which prevented the experiments being so decided, as the dressings were put on indiscriminately upon the land before it was known."

Remarks.—The only remark I need make upon these experiments is, to suggest to my readers that, by repeating the above trials upon oats with Mr. Fleming's *mixtures*, they may not only benefit their own crops, but may also aid materially in the advancement of practical agricultural knowledge.

7.—*On the effect of Sulphate of Soda applied as a top-dressing to Beans and Pease.*

"The first dressing was applied the 4th of May, on some beans on a border in the garden; the drills that were dressed quickly took the lead of the others. There was no alteration of colour, but greater strength, and it *tillered wonderfully*. There were five or six stems from every seed sown, and the pods were larger and more numerous, and the beans in the pods a great deal larger than the same variety undressed. It was also put upon some of the ridges of the beans in the field, and with the same effect, and gave a very large crop (not yet thrashed.)

"Upon pease in the garden it appeared to add little, if any thing, to the strength of straw, but those that were dressed had a far greater number of pods, and those better filled, and the pease of a better flavour, and *it seems a valuable dressing for all leguminous crops*. When sown in the drills along with the pease, it nearly killed every one of them, while the same quantity, put on as a top-dressing to some drills next to them [where the pease were two inches high,) did no injury."

Remarks.—The testimony of Mr. Fleming to the value of sulphate of soda as a dressing for leguminous crops, is very valuable and satisfactory. We may hope that next year will furnish us with experiments, *all* the results of which shall have been so carefully ascertained, as to enable us to decide upon the economical value of this sulphate as a manure, by a comparison of the amount of increase in the crop, with the cost of the application.

8.—*On Nitrate of Soda as a top-dressing to Gooseberry and Currant bushes.*

"It was applied April 14th, at about the rate of ½ cwt. per acre, or ½ lb. per bush. It had the effect, in the course of a week, of producing on the bushes a dark green colour and broader leaves, and the fruit set better and more plentifully, especially on some red currants that had borne little for two years. These set their fruit well, and yielded double their former produce. The dressed bushes kept the lead in strength and vigor all the season, and now, when the undressed bushes have lost their leaves, the others are quite green."

9.—"Many experiments were tried in the garden on turnips, by top-dressing with nitrate of soda, but with no perceptible effect. However, the Swedish and red-top yellow, in a field of rather stiff soil, were benefitted, the former yielding ¼ more produce in weight, and the latter ⅙ more weight.

"*Barochan, 26th October*, 1841. Wm. Fleming."

Note.—The prices paid by Mr. Fleming were as follow:—Bone dust (fine) 1s. 9d. per bushel; sulphate of ammonia (in crystals) 28s. per cwt.; potash (very impure) 24s. per cwt.; sulphate of soda (in crystals) 5s. per cwt.; nitrate of soda 22s.; and sal-ammoniac 60s. per cwt.

No. IV.

SUGGESTIONS FOR COMPARATIVE EXPERIMENTS WITH GUANO AND OTHER MANURES.

Guano is the name given in South America to the dung of the sea fowl which hover in countless flocks along the shores of the Pacific, and which, from time immemorial, have deposited their droppings on the rocks and the islands which are met with along the coast of Peru.

Besides the fresh white guano which is deposited year by year in these localities, there exist, in some spots, large accumulations more or less buried beneath a covering of drifted sand, which have been thus buried and partially preserved from an unknown antiquity. This ancient guano is of a brown colour, more or less dark, and forms layers or heaps of limited extent, but which are said sometimes to exceed even 60 feet in thickness.

In the time of the Incas this substance was known and highly valued as a manure,—the country along the coast for a length of 200 leagues was entirely manured by it,—the islands on which it was formed were carefully watched and preserved,—and it was declared to be a capital offence to kill any of the sea fowl by which it was deposited. Ever since that time it has been more or less employed for the same purpose, and much of the culture now practised on this thinly-peopled coast is entirely dependent for its success, if not for its existence, on the stores of manure which the sea fowl thus place within reach of those parts of the country which are susceptible of cultivation.

In modern times, however, the access of foreign shipping, and the want of careful protection, have driven away many of the sea fowl, and lessened to a very great degree the production of the recent guano. Thus the country is more dependent than in former times on the more ancient deposits, which are now assiduously sought for, and when discovered beneath the sand, are carefully excavated and transported to the sea-ports for sale.

The dung of birds of all kinds, when exposed to the air, gradually undergoes decomposition, gives off ammonia, and acquires a brown colour. As this ammonia is one of the most fertilizing substances it contains, it will be readily understood that the old brown guano is much less valuable as a manure than that which is recent and white; hence the care of the ancient Peruvians in collecting the fresh, and their comparative neglect of the ancient guano.

When the brown guano is put into water, a large quantity of it—sometimes 70 per cent. of the whole—is dissolved. Hence, it is, because the climate of Peru is so dry and arid that in the plains rain scarcely ever falls, that the guano can accumulate as it is found to do. North and south of this line of coast, where rains are less unfrequent, such accumulations are not met with, though the birds appear equally plentiful, and it may be safely stated that, had the climate of Peru been like that of England, the rains would have washed the guano from the rocks almost as rapidly as it was deposited.

Of the brown guano several cargoes have lately been brought to England by an enterprising merchant in Liverpool, and it has been deservedly recommended to the attention of British agriculturists. It has already been tried upon various crops, both of hay and corn, upon turnips also, and upon hops, and there can be no doubt whatever that in our climate, as well as in that of Peru, it is fitted to promote vegetation to a very remarkable degree.

This brown guano varies much in quality, according probably to the degree of exposure to the air to which it has been subjected, or to its position in the deposit from which it has been dug. Two different portions, taken at random from the same box, gave me the following very different results:—

1°.—Water, salts of ammonia, and organic matter, expelled by a red heat.	23·5	per ct.
Sulphate of soda.	1·8	"
Common salt, with a little phosphate of soda.	30·3	"
Phosphate of lime, with a little phosphate of magnesia and carbonate of lime.	44·4	"
	100[*]	

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[*] The first contained also 8 per cent. and the second 1½ per cent. of sand, which has been left out of the true composition of the guano considered as free from sand.

2°.—Ammonia	= 7·0	59·3 per ct.
Uric acid	= 0·8	
Water, carbonic and oxalic acids, &c., expelled by a red heat,	= 51·5	
Common salt, with a little sulphate and phosphate of soda		11·4 "
Phosphate of lime, &c.		29·3 "
		100

According to M. Winterfeldt, this brown guano is sold at the ports near which it is obtained at about 3s. a cwt. It might, therefore, if this be correct, be imported into this country, and sold at less than 10s. per cent. The price at present asked, however, is 25s. per cent., a cost at which it is doubtful if the English agriculturist can afford to use it.

In any case it seems improbable that the guano can continue to be imported into this country for any length of time. It is absolutely necessary to the cultivation of the land in Peru,—and it is also diminishing in quantity,—the first settled government, therefore, which is formed in that country, must prohibit the further exportation of a substance so important to the national interests. It is a matter not unworthy of the attention of chemists, therefore, to consider whether a mixture similar to the guano, and of equal efficacy, cannot be formed by art—not only at a cost so reasonable as at once to make the British farmer independent of the importer,—but also in such abundance as at the same time to place so valuable a manure within the reach of all.

The following mixture contains the several ingredients found in guano in nearly the average proportions; and I believe it is likely to be at least as efficacious as the natural guano, for all the crops to which the latter has hitherto been applied in this country:—

	£.	s.	d.
315 lbs. (7 bushels) of bone dust at 2s. 9d. per bushel	0	19	0
100 lbs. of sulphate of ammonia,* containing 26 lbs. of ammonia at 20s. a cwt.	0	18	0
5 lbs. of pearl-ash	0	1	0
100 lbs. of common salt	0	2	0
11 lbs. of dry sulphate of soda	0	1	0
531 lbs. of *artificial guano* cost	2	1	0

The quantity here indicated may be intimately mixed with 100lbs. of chalk, and will be fully equal in efficacy, I believe, to 4 cwt. of guano, now selling at £5.

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* Sulphate of ammonia is now manufactured largely at Glasgow, and may be had for less than 20s. a cwt.

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